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SYSTEMS AND METHODS FOR SHARING CONTENT IN AN EXTENDED REALITY ENVIRONMENT

Abstract

Systems and methods are disclosed herein for establishing a communication path between devices that are virtually proximate in an XR environment. First and second user devices are connected to the same space in a virtual environment (VE). The first user device is externally connected to a media device. Device information about the media device is retrieved, and a virtual device for the media device is generated in the space. The virtual device is selected. A communication path between the first and second user devices is identified based on their respective connections to the same space. A virtual connection is generated based on the identified communication path for providing media content between the media device and the user devices.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS [0001] This application is a continuation of U.S. patent application Ser. No. 18/142,636, filed May 3, 2023 (now allowed), the disclosure of which is hereby incorporated by reference herein in its entirety.

BACKGROUND
[0002] The present disclosure is generally directed to systems and methods for sharing content from a first device to other devices bridged via an extended reality (XR) environment.
SUMMARY
[0003] Extended reality (XR) environments are emerging as a new paradigm for socializing and interacting in personal and professional settings. As XR environments continue developing (e.g., in metaverse applications), scenarios may arise where users may request a virtual environment (VE) having experiences and interactions analogous to a realistic environment, such as being able to wirelessly link devices (e.g., connecting via Bluetooth).
[0004] A connection utilizing a radio frequency (RF)-based transmission (i.e., an RF-based connection) between devices cannot be established for user devices through a VE when the devices are not physically nearby (e.g., when the devices are in different geographical locations). For example, a user device may request to connect with a media device (e.g., a Bluetooth speaker, an Internet-of-Things (IoT) device, a smart hub, etc.) via an RF-based protocol or transmission medium (e.g., Bluetooth and its variants, a Wi-Fi network, Zigbee, Amazon Sidewalk, a cellular network, etc.). In some instances, the user device may store device information of the media device for subsequently generating the RF-based connection (e.g., pairing information). In such an approach, devices may be wirelessly connected if the devices are located within a physical proximity constrained by the RF-based connection (e.g., inside the same room or within a short range such as 30 feet).
[0005] As an illustrative example, connectivity under Bluetooth 5.0 may be limited to a physical range of about 100 feet under some circumstances due to the medium (e.g., air) of radio frequency (RF) transmission and/or various interferences (e.g., by a building wall). In this example, a first device (e.g., a hands-free audio player, a digital assistant, or a video display) designed to establish a communication path via Bluetooth could share the first device's functionality with a second device (e.g., a virtual reality (VR) or augmented reality (AR) headset) that is physically located within 100 feet of the first device but loses reliability outside this range. In this or other RF-based approaches, devices lack a way to establish a virtual connection when virtual representations of the devices are in the same VE since RF-based transmission is limited by a physical range.
[0006] In another approach, a mesh network may connect separate networks, for example, using an RF-based connection between outdoor access points (e.g., to connect neighboring buildings) and forward data based on the hardware address of the devices in the networks. An RF-based connection between access points is limited by the physical range of the RF transmission as in other approaches and can be subject to wireless interference. Further, in this approach and similar approaches that involve linking networks of devices, a communication path from a first device to a second device may include intervening nodes, checkpoints, routers, hubs, etc., which may contribute to latency and other connectivity characteristics that impact data transmission. The aforementioned issues may render such approaches unsuitable for XR systems and/other VE systems that rely on near real-time synchronization.
[0007] Thus, there is a need for connecting devices within a virtual proximity in an extended reality environment.

[0008] To overcome the aforementioned limits and unsatisfactory aspects of other approaches, systems and methods are presented for establishing a communication path between devices that are virtually proximate in an XR environment. One or more disclosed embodiments may enable sharing a connected media device (e.g., via an RF-based connection) through a communication path established in an XR environment. In some aspects, the present disclosure describes an XR framework that includes an XR environment system and/or an XR engine for generating and establishing a virtual network bridge configured to proxy device connections from a remote device and/or other devices linked to the remote device. In some aspects, one or more disclosed embodiments describe an XR framework including a network architecture that may spawn a programmable virtual network bridging a first device and one or more linked devices, where the XR system is configured to virtually pair devices using the virtual network. In some embodiments, the virtual network may be modeled based on a local network, and/or programmed to mimic the network functions, between devices at the same geographic location through virtualized components in the XR framework. In some aspects, the present disclosure describes an XR framework that generates a virtual application interface that enables an application at a device to communicate and interact with virtualized devices, or virtual devices, in a VE.
[0009] In some embodiments, an XR framework determines that a first user device and a second user device are connected to the same virtual space in a VE, wherein the first user device is paired and/or connected with a media device local to the first user device. Based on the pairing between the first user device and the media device, the XR framework may generate and/or present a virtual representation of the media device in the virtual space. The XR framework may receive a selection of the virtual representation of the media device, for example, from the second user device. The XR framework may generate a communication path that shares media content and/or device information between the media device, the first user device, and the second user device. In some embodiments, the XR framework may generate a virtual connection including a virtual bridge for sharing data between the media device, the first user device, and the second user device.
[0010] In some embodiments, an XR framework may determine that a first user device and a second user device are connected to the same virtual space in a VE, wherein the first user device is externally connected with a media device. The XR framework may retrieve device information corresponding to the media device. The XR framework may generate, based on the device information, a virtual representation of the media device in the same space. The XR framework may receive a selection of the virtual representation of the media device. The XR framework may identify a communication path between the first user device and the second user device based on the respective connections of the first user device and the second user device to the same virtual space. The XR framework may generate, based on identifying the communication path between the first user device and the second user device, a virtual connection for providing media content between the media device, the first user device, and the second user device.
[0011] In some embodiments, an XR framework may share content between virtually proximate devices using a virtual connection. As an example, a first XR device may be connected wirelessly (e.g., via Wi-Fi) to a smart TV display device displaying a movie. In this example, the XR framework may receive the movie and other associated data via the first XR device and generate a TV avatar in a VE representing the smart TV display device. The XR framework may generate the movie for display on the TV avatar and, in some instances, synchronize presentation of the movie on the TV avatar and at the smart TV display device. A second XR device may connect to the smart TV display device using a virtual connection. The second XR device, via an interactive virtual avatar, may interact with the TV avatar and view the movie at the TV avatar through the VE. In some embodiments, the second XR device is externally connected to a media device (e.g., via a local network). The second XR device may transmit the received movie for playing at the connected media device. In some embodiments, the XR framework extends a virtual connection to include the external connection between the second XR device and the second media device.

[0012] In some embodiments, the XR framework may generate a virtual bridge between a plurality of user devices for sharing content in a VE. For example, a plurality of user devices may receive music from a concert by having associated user avatars attend a virtual representation of the concert rendered in a VE through the XR framework. One or more user devices of the plurality of devices may be connected to a media device near to the one or more user devices. The XR framework may generate a virtual network that provides the music for playing at the nearby media device. In some instances, where each user device is connected to a respective media device, the XR framework, using the virtual network, may synchronize playing of the music at the respective media devices. In this manner, users may experience the virtual concert as a group, for example, through their user devices (AR/VR headsets, smartphones, etc.) supplemented by other devices (e.g., wireless speakers, displays, etc.) when the user devices are geographically remote and virtually proximate.
[0013] In some aspects described herein, an XR framework may enable a remote user device outside the physical range of RF-based connections to detect electronic devices in an advertising or discoverable mode (e.g., available for pairing). The advertising devices may be physically located and/or linked to a first user device via RF-based transmission (e.g., Bluetooth). For example, the first user device may open an external connection with a Bluetooth speaker for pairing with a second user device that is outside the Bluetooth speaker's connectivity range. The Bluetooth speaker, via the first user device, may provide music or other audio content when both the first and second user devices are virtually proximate (e.g., within an XR environment or other virtual space). At the second user device, the Bluetooth speaker may be shown as discoverable in a user interface for connecting to discoverable devices including RF-based connections. Additionally, or alternatively, the user interface may include a section for connecting to devices through a virtual connection.
[0014] As a result of the described systems and techniques, devices within a virtual proximity in an extended reality environment may be interconnected for sharing device functionality and/or content, improving on other approaches or lack thereof. For example, virtually proximate user devices may connect and share physical devices through the XR environment (e.g., in metaverse-based applications). For example, users at different geographic locations may share RF-based devices with an interactive environment through the XR framework that is missing in other approaches. Additionally, as a result of the described systems and techniques, the XR framework may improve system resource usage (e.g., computing cycles, memory allocation, traffic networking, etc.) by establishing an efficient communication path (e.g., a virtual bridge) having fewer intervening nodes and lower latency, among other benefits, between virtually paired devices. For example, the XR framework may generate multicast protocols directing traffic from a media device to a plurality of user devices connected via a virtual bridge. For example, the XR framework may determine an optimal communication path (e.g., shorter, faster, more reliable, more stable, etc.) between devices as part of the virtual connection. Thus, the XR framework of the present disclosure addresses the aforementioned issues and other unsatisfactory aspects.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0015] The present disclosure, in accordance with one or more various embodiments, is described in detail with reference to the following figures. The drawings are provided for purposes of illustration only and merely depict typical or example embodiments. These drawings are provided to facilitate an understanding of the concepts disclosed herein and should not be considered limiting of the breadth, scope, or applicability of these concepts. It should be noted that for clarity and ease of illustration, these drawings are not necessarily made to scale.

[0016] FIG. **1** shows an example scenario of an XR framework bridging virtually proximate devices, in accordance with some embodiments of this disclosure;
[0017] FIG. **2** shows an example scenario of an XR framework linking a device associated with a virtual representation at a virtual event in a virtual environment with a group of virtually proximate devices, in accordance with some embodiments of this disclosure;
[0018] FIG. **3** shows an illustrative system for consuming content (e.g., media content, XR content, etc.), in accordance with some embodiments of this disclosure;
[0019] FIG. **4** shows illustrative user equipment for consuming XR content including an example XR device, in accordance with some embodiments of this disclosure;
[0020] FIG. **5** is a flowchart of an example process for connecting virtually proximate devices, in accordance with some embodiments of this disclosure;
[0021] FIG. **6** is a flowchart of an example process for sharing content to virtually proximate devices, in accordance with some embodiments of this disclosure;
[0022] FIG. **7** is a flowchart of an example process for establishing a virtual connection between virtually proximate devices, in accordance with some embodiments of this disclosure;
[0023] FIG. **8** is a flowchart of a detailed illustrative process for connecting virtually proximate devices and sharing content between the devices, in accordance with some embodiments of this disclosure.

DETAILED DESCRIPTION

[0024] Systems and methods are described herein for an XR framework connecting devices within a virtual proximity in an extended reality environment.
[0025] As referred to herein, the term “content” should be understood to mean an electronically consumable asset accessed using any suitable electronic platform, such as broadcast television programming, pay-per-view programs, on-demand programs (as in video-on-demand (VOD) systems), Internet content (e.g., streaming content, downloadable content, Webcasts, etc.), video clips, audio, haptic feedback, information about content, images, animations, documents, playlists, websites and webpages, articles, books, electronic books, blogs, chat sessions, social media, software applications, games, virtual reality media, augmented reality media, and/or any other media or multimedia and/or any combination thereof. Extended reality (XR) content refers to augmented reality (AR) content, virtual reality (VR) content, hybrid or mixed reality (MR) content, and/or other digital content combined therewith to mirror physical-world objects, including interactions with such content.
[0026] As described herein, the term “virtual environment” and its variants refer to an artificial, interactive, digitally generated scene or world and include immersive media and/or 4D content. As described herein, the term “virtual space” and its variants refer to a space having defined bounds in a VE and within which models, avatars, and/or other virtual representations of physical objects (e.g., a digital twin) may engage, communicate, and interact, among other activities. As described herein, the term “virtual proximity” and its variants refer to digital models and/or other such representations being perceived as close to one another in the VE, including, but not limited to, a proximity threshold, virtual contact, collision detection, the models' position in a virtual space, the models' coordinates in a virtual space, and/or an information exchange that establishes protocols for a communication link. As described herein, the terms “virtual bridge” or “virtual device bridge” refer to a virtualized networking component (e.g., network bridge device) that joins two or more communication paths and/or forms a virtual network, which communicatively couples the devices in the virtual network. A communication path including a virtual bridge may be referred to as a virtual connection. As described herein, the term “external link” and its variants refer to a communication path, including wired and RF-based connections, between devices that are within a connectivity suitable for such connections (e.g., physically proximate) without coupling devices using a virtual bridge via an XR framework.
[0027] As described herein, an XR framework may include hardware, software, firmware, and/or

any combinations of components thereof, where any of the involved systems may perform one or more of actions of the described techniques without departing from the teachings of the present disclosure. It is noted and appreciated that reference to an XR framework is provided for conciseness and may refer to one or more parts of the XR framework, and combinations thereof, that performs the described actions. Some non-limiting examples are described as follows. For example, an XR framework may include a locally hosted application at a user device. For example, an XR framework may include a virtual network between various devices. For example, an XR framework may include a remote application such as an XR environment system hosted at a server communicatively coupled to one or more user devices and other systems linked to a user device, where the XR environment system provides instructions that are transmitted to the user devices and executed by the relevant systems at the location of the user devices. For example, an XR framework may include a subsystem integrated with user equipment. For example, an XR framework may include a local application hosted at user equipment and a remote system communicatively coupled therewith.

[0028] Although described in the context of XR content and devices herein, it is noted and appreciated that the systems and techniques described herein are intended to be non-limiting and may be applicable within other contexts. For example, a virtual environment may include other digitally generated settings (e.g., a world in a gaming application). For example, an XR framework may include servers and applications for rendering various virtual environments. For example, virtual representations may include user avatars that are generated and/or projected for a physical location (e.g., for viewing a physical sporting event). For example, participants using a videoconferencing or teleconferencing application may be virtually proximate by attending the same videoconference or accessing the same breakout session within the videoconference. The participants may establish a virtual connection via their devices (e.g., a personal computer, a conferencing system hub, etc.). A virtual connection may be applicable for various situations, including MR scenarios. The examples described herein are illustrative, and the described techniques may be extended to include the various situations.

[0029] FIG. **1** shows an example scenario **100** of an XR framework **102** bridging virtually proximate devices **104** and **106**, in accordance with some embodiments of this disclosure. In scenario **100**, the XR framework **102** may be communicatively coupled to the devices **104** and **106** via communication paths **108** and **109**, respectively. It is noted that paths **108**, **109** may include a plurality of paths, networks, intervening nodes, edge servers, etc. Paths **108**, **109** are described as single paths for conciseness, which is intended to be non-limiting and may include various configurations for paths **108**, **109** as described in the following paragraphs with respect to FIG. **1**. As described herein, the XR framework **102** may establish a communication path between devices (e.g., a virtual connection), which can include portions of paths **108**, **109**. The devices **104** (labeled DR1) and **106** (labeled XR2) may be associated with user and/or device identifiers **105** and **107**, respectively.

[0030] The XR framework **102** may generate a virtual environment **130** including various virtual objects such as models **132**, **136** corresponding to externally linked media devices **112**, **116**. The first user device **104** may be associated with a first user profile (labeled User A) and an avatar **144** in the VE **130**. The second user device **106** may be associated with a second user profile (labeled User B) and an avatar **146** in the VE **130**. The avatars **144**, **146** may be in the same virtual space **140** in the VE **130**. For example, the avatars **144**, **146** may digitally represent respective users of the devices **104**, **106** based on information from the respective user profiles. In some embodiments, the XR framework **102** may generate a virtual space **140** including virtual representations associated with user devices **104**, **106** and/or associated with respective user profiles. For example, the avatars **144** and **146** in the VE **130** may be respectively associated with the devices **104** and **106**. For example, the avatars **144** and **146** may be associated with user profiles (e.g., respectively labeled User A and User B). Actions of the avatars **144**, **146** in the VE **130** may be controlled via the user devices **104**, **106** (e.g., via a gaming control device externally linked to the device **106**). Indicators **147**, **148** may be displayed in the VE **130** and indicate the corresponding user/device identifiers **105**, **107** for the avatars **144**, **146**. For example, the devices **104** and **106**, via their respective display screens, may show viewpoints as presented in the VE **130** in the scenario **100**. For example, each of devices **104** and **106** may display a respective viewpoint of the VE **130** as viewed from the respective avatar **144** or **146**. In some embodiments, the XR framework **102** may generate the viewpoints and transmit the corresponding graphical data to be presented at respective displays of the devices **104** and **106**. In some embodiments, the devices **104**, **106** generate the avatars **144**, **146** and their respective viewpoints, and the XR framework **102** generates the virtual objects in VE **130**. The XR framework **102** may transmit relevant point-of-view (POV) information for the devices **104**, **106** to update the respective viewpoints of the avatars **144**, **146**.

[0031] In some embodiments, the XR framework **102** may include an XR environment system for generating the VE **130** and XR content in the VE **130**. For example, the XR framework **102** may include an XR engine that generates the VE **130** and representations for various digital assets of the VE **130**. In some embodiments, the XR framework **102** is communicatively coupled to an XR environment engine. The XR framework **102** may provide instructions to the XR environment engine, based on activities/events in the VE **130**, that cause the XR environment engine to perform some or all of the actions to generate, update, and maintain the VE (e.g., 3D modeling, asset processing, graphics processing, environment updating, etc.). The XR framework **102** may present the VE **130**, or frames thereof, at devices **104** and/or **106**. The example configurations of the XR framework **102** and paths **108**, **109** described herein are intended to be illustrative and non-limiting. It is contemplated that an XR framework and the communication paths may have various configurations and/or combinations of hardware, software, firmware, etc., suitable for performing the functions described herein without departing from the teachings of the present disclosure.

[0032] The device **106** may be outside the connectivity range for devices **112** and **116**. For example, the device **106** may be geographically remote from the physical location **110**. For example, the device **104** may be located in Vancouver and the device **106** may be located in Chicago. The device **106** may be associated with device/user identifier **107**. In the scenario **100**, the device **106** may be an XR head-mounted device (HMD) or other wearable device for interacting with an XR environment such as the VE **130**. In some instances, the VE **130** may be modeled based on a physical location or setting (e.g., a café, a concert venue, location **110**, an arena, a sport venue, etc.). In some instances, the VE **130** may be modeled based on a fictional location or setting (e.g., a sci-fi environment, a historical setting, a futuristic setting, a fantasy world, an imaginary landscape, etc.).

[0033] The XR framework **102** may generate a virtual user interface (UI) **150** including UI elements **152-160**. For example, the virtual UI **150** may include a UI identifier **152** (e.g., a title "Virtual Bridge"), an interactive icon **154** (e.g., button, toggle, switch, etc.), and a device status indicator **156**. The virtual UI **150** may include a list of available devices in the VE **130** (labeled VE devices). In some embodiments, the virtual UI **150** may include a list of externally linked devices for the device **106** (e.g., labeled other devices). For example, the list may include a device connectivity status indicator **158** and an interactive icon **160** for accessing supplemental information of an available device (e.g., for additional device and/or connection information). For example, the virtual UI **150** may be displayed in the VE **130** for the device **106**. The virtual UI **150** may be presented as an overlay (e.g., a floating screen) from the viewpoint of the device **106** in the VE **130**.

[0034] Referring to scenario **100**, the device **104** may be located in a physical location **110**. The location **110** may include media devices **112** and **116**. As an illustrative example, the location **110** may be a household with device **112** being a smart TV and device **116** being a wireless audio output system (e.g., including one or more wireless speakers). In this example, device **112** may be currently displaying video/audio content **114**. Devices **112** and **116** may be paired and/or connected to device **104** in the location **110** (e.g., via Bluetooth, Wi-Fi, etc.). As described herein, devices **112** and **116** are externally linked to device **104**. Device **104** may be associated with a device/user identifier **105**. Device **104** may have an interactive UI element or option **118** to enable a sharing or discovery mode of one or more externally linked devices. For example, a user via the device **104** may turn on sharing for a paired device (e.g., device **116**), which enables one or more user devices, having avatars within a configurable virtual proximity to the avatar **144** in the VE **130**, to see advertisement packets from the paired device.

[0035] In the scenario **100**, the first user device **104** may be externally linked to the devices **112**, **116**. The first user device **104** may enable a discovery mode for one or more externally linked devices through selection of option **118**. The XR framework **102** detects that device **116** is discoverable via path **108** and the first user device **104**. For example, the device **116**, when discoverable, may broadcast, or allow access/retrieval of, connection and device information (e.g., Internet Protocol (IP) address, public authentication data, public access key, pairing information, etc.). The XR framework **102** may access/retrieve the relevant information for connecting to the device **116** via path **108** and the first user device **104**. Based on the device **116** being discoverable, the XR framework **102** may generate the model **136** as an interactive element in the VE **130**.

[0036] Continuing the scenario **100**, the XR framework **102** determines that the devices **104** and **106** are virtually proximate. For example, the devices **104** and **106** may be within a virtual proximity based on the VE **130**. For example, in the scenario **100**, the avatars **144**, **146** may access the same virtual space **140**. Additionally, or alternatively, the avatars **144**, **146** may exchange a virtual handshake or other interaction in the VE **130** that establishes protocols and/or acceptance of a communication link between the devices **104**, **106**. For example, the devices may exchange connection information including transfer rate, coding alphabet, parity, interrupt procedure, various security measures, etc. For example, the devices may exchange protocol data for initiating a communication in the VE. In some instances, exchanging the protocol data may include exchanging user identifiers. For example, if the virtual space **140** is a virtual social space (e.g., a social media platform), the devices may exchange usernames, enabling social communication between the avatars in the VE **130** (e.g., a friend request), which may be indicative of the devices being virtually proximate. Based on the virtual proximity status of the devices **104**, **106**, the XR framework **102** may generate a notification for the device **106** that indicates device **116** is available. In some embodiments, the XR framework **102** may broadcast, or allow access/retrieval of, the connection and device information for device **116** based on virtual proximity to the avatar **144** in the VE **130**. For example, the XR framework **102** may determine an area around the avatar **144** as a virtual proximate area. For example, the XR framework **102** may determine a perimeter around the avatar **144** as a proximity threshold by defining a range based on distance from avatar **144** in the VE **130**. In some embodiments, the XR framework **102** may determine that the device **106** is in discovery mode, for example, based on the mode toggled on via icon **154**. The XR framework **102** may update the status indicator **156** and broadcast an availability status for the device **106** on one or more connections and/or based on a virtual proximity range from the avatar **146**.

[0037] In some embodiments, the XR framework **102** may generate virtual representations corresponding to various physical devices for display in the VE **130**. For example, the XR framework **102** may generate, based on the external connection of devices **112** and **116** to device **104**, a virtual model **132** to represent the device **112** and a virtual model **136** to represent the device **116**. For example, the XR framework **102** may access device information for the device **112** via the device **104**. Examples of device information may include device make, device model, serial number, media access control (MAC) address, IP address, geolocation data, advertising ID, available applications, software version, firmware version, operating system information, etc. In this example, the XR framework **102** may determine a virtual representation of the device **112**, for example, by accessing a database comprising a plurality of devices and associated information and identifying specifications (e.g., dimensions, size, weight, screen size, etc.) for the device **112** based on the device information such as the make, model, and serial number. The XR framework **102** may generate a model **132** of the device **112** from the specifications and position the model **132** in the VE **130**. For example, the model **132** may be placed at a position relative to the position of device **112** at location **110**. In a similar manner, the XR framework **102** may generate the model **136** for device **116**. The virtual models **132**, **136** may include display of respective indicators **134**, **138** (e.g., device IDs). Indicators **134**, **138** may be indicative of a device status, for example, by including a status label. Examples of a device status include active, inactive, sleep mode, offline, paired, pairing mode, connected, discoverable, etc. Indicators **134**, **138** may include icons or other graphical elements (e.g., a green/red light, an animation, a spinning circle, etc.).

[0038] Referring to the scenario **100**, the device **112** may be displaying content **114** comprising video and/or audio content. The XR framework **102**, via the path **108** and the device **104**, may determine that the device **112** is displaying content **114** and establish a virtual connection, including a virtual bridge, for receiving the content **114**. For example, the virtual bridge may couple the XR framework **102** and the device **112**. The XR framework **102** may identify a communication path between the first and second user devices based on their respective connections to the XR framework **102** (e.g., to the same virtual space hosted in the XR framework **102**). In some embodiments, the XR framework **102** may perform one or more path optimization techniques and generate an optimized virtual connection between virtually proximate devices. For example, the device **112** may transmit content **114** to the device **104** via the corresponding external link, and the device **104** may transmit the content **114** to the XR framework **102** via a virtual connection. For example, the XR framework **102** may generate an optimized communication path bridging the device **112** and the XR framework. The optimized communication path may include path **108** or parts thereof. The XR framework may receive the content **114** via a virtual connection and present the content **114** to the VE **130** using the model **132**.

[0039] A second user device (e.g., device **106**) may view and/or interact with the content **114** in the VE **130** using the avatar **146** to control the model **132** in various ways (not shown in the scenario **100**). Some interactions between avatar **146** and model **132** include the following illustrative, non-limiting examples. For example, the avatar **146** may select an option from a virtual UI that corresponds to the model **132**. For example, the avatar **146** may tap a part of the model **132** that is assigned as a control interface in the VE **130**. For example, the avatar **146** may speak a voice command received at the device **106** (e.g., from a user at the device **106**). Based on the received input (e.g., interaction, selection, voice command, etc.), the XR framework **102** may modify the content **114** at the model **132** (e.g., pausing the content **114**). For example, the avatar **146** may reduce the volume or select one or more trick-play functions for the content **114** at the VE **130** by sending commands through the model **132**. In some embodiments, the XR framework **102** may transmit an instruction, via the virtual connection, that is configured to modify the presentation of content **114** (e.g., play back, audio/video settings, etc.) at the device **112** based on the interactions with the model **132** and/or commands received in the VE **130**. Some example operations include pause, play, fast-forward, rewind, slow-motion, other trick-play operations, record, adjust volume and/or other audio settings, etc. For example, the XR framework **102** may synchronize the presentation of content **114** at the device **112** and the model **132** via the virtual connection. For example, the XR framework **102** may transmit an instruction that is configured to cause reduction of the volume or execution of a trick-play function at the device **112** based on a voice command from the avatar **146**. For example, the XR framework **102** may receive a selected option that pauses presentation of the content **114** from the device **106**. The XR framework **102** may transmit an instruction that pauses presentation of the content **114** at both device **112** and at the model **132**. For example, the XR framework **102**, based on receiving a selection of another option, may cause the presentation of the content **114** at device **112** to be paused and the content to play in slow motion and/or to record at the model **132**. It is contemplated that the interactions between the virtually proximate devices have various configurations enabled via a virtual connection through the XR framework, including the aforementioned example operations.

[0040] The device **106** may request a connection to device **116** via the VE **130**. In some embodiments, the avatar **146** may select or otherwise interact (e.g., via interaction **149**) with the model **136** to request the connection between the devices **106** and **116**. In some embodiments, the XR framework **102** may generate, modify, and/or update one or more elements of the virtual UI **150** for receiving a selection at the device **106**. For example, in response to determining that the devices **104** and **106** are virtually proximate, the XR framework may add the device indicator **138** to a list of discoverable devices in the virtual UI **150**. A corresponding status indicator **158** may be updated to notify that the device **116** is available. An interactive icon **160** may be included for accessing supplemental information about device **116** (e.g., the connection details, IP address, etc.).

[0041] As an illustrative example, one or more participants of a videoconference may establish a virtual connection between their respective devices that are accessing the videoconference session. A presentation device may be accessible to the participants via the virtual connection. The presentation device, via the virtual connection, may share a slideshow display or other visual content between the videoconference participants. The XR framework **102** may generate an interactive icon or a virtual model of the presentation device for shared display. One or more participant devices may select the icon or model to establish the virtual connection. The presentation device and/or virtual model may be configured to enable a participant device to interact with the slideshow content without affecting the shared display. For example, a participant device may select the virtual model. An XR framework may generate for display an instance of the virtual model at the participant device via the virtual connection and the videoconferencing system. A participant, via the participant device, may interact with the instance of the virtual model, for example, to view an earlier displayed slide at the participant device without changing a currently viewed slide in the shared display of the slideshow content.

[0042] The XR framework **102** may generate a virtual connection between the devices **104** and **106** based on their virtual proximity. For example, upon receiving selection of the device **136** (e.g., via interaction **149** and/or UI **150**), the XR framework **102** may generate a virtual connection between the device **116**, the device **104**, and the device **106**. In some aspects, the virtual connection links the paths **108** and **109**, which enables sharing of externally linked devices with the devices **104** and/or **106** (e.g., sharing the device **112** with the device **106**). For example, the XR framework **102** may cause devices **104** and/or **106** to perform one or more functions of a proxy server for sharing externally linked devices. For example, the XR framework **102** may generate a virtual proxy device at the device **104** for transmitting the content **114** from the device **112** to the device **106** via the virtual connection. In some embodiments, the XR framework **102** may generate a virtual connection configured as a stable, dedicated communication path between the devices **104** and **106** and/or one or more externally linked devices. For example, the virtual connection may include paths **108**, **109** and an external link between device **104** and device **112**. In some embodiments, the XR framework **102** may share one or more applications and associated data (e.g., via an application programming interface (API)) between the devices **104** and **106** using the virtual connection. The capabilities of the device **104** may be available to the device **106**. For example, a gaming application may be hosted and/or otherwise accessible at the device **104**. A virtual bridge may enable the device **106** to access the gaming application that device **104** has permitted (e.g., allowing device **106** to transmit control instructions remotely for the gaming application). In some embodiments, the XR framework **102** may dynamically generate, maintain, and remove virtual connections between virtually proximate devices. For example, if the sharing mode for device **116** is deactivated at device **104**, the XR framework **102** may detect that the sharing mode has ended and remove the corresponding virtual connection (e.g., between paths **108**, **109**).

[0043] As a detailed illustrative example for the scenario **100**, a first user device **104** may be externally linked to user equipment (e.g., a home theater system including devices **112**, **116**). The first user device **104** may be connected to a VE **130** (e.g., via a metaverse-based application) generated and/or hosted at a server of the XR framework **102**. In this instance, a first communication path **108** between the first user device **104** and the server may include a first plurality of intermediate nodes (e.g., edge servers). The XR framework **102** may dynamically configure the network topology of the first communication path **108**, for example, by selecting and deselecting intermediate nodes and/or arranging path segments between nodes to ensure a stable, reliable data transmission rate from the server to the first user device **104**. In a similar manner, a second user device **106** may be connected to the same server or another server of the XR framework **102** through a second communication path **109** (e.g., via a second plurality of intermediate nodes). In this instance, the XR framework **102** may generate a virtual connection from the first user device to the second user device through manipulation of the network topology for paths **108**, **109**. In one instance, if the paths **108**, **109** have an intermediate node in common, the XR framework **102** may virtually bridge the paths **108**, **109** by routing the data through the intermediate node. The XR framework **102** may generate a data structure for the devices that are linked via the virtual connection (e.g., a forwarding database, a forwarding information base, a MAC table, a relational database, in associative memory or cache, etc.). The data structure may include the information (e.g., device IDs, addresses, etc.) for directing data traffic transmitted via the virtual connection.

[0044] Continuing this illustrative example, the XR framework **102** may determine a third communication path (not shown) between the first user device **104** and the second user device **106**. The third communication path may include portions of paths **108**, **109** and/or a different plurality of nodes. In one instance, the XR framework **102** may map one or more nodes between the first and second plurality of intermediate nodes and, based on the mapping, determine the third communication path (e.g., using a pathfinding technique). Some examples of pathfinding techniques include Dijkstra's algorithm and its variants (e.g., A* algorithm), hierarchical path finding, multi-agent planning, incremental heuristic search-enhanced pathfinding, Viterbi algorithm, Johnson's algorithm, Floyd—Warshall algorithm, Bellman—Ford algorithm, etc. In some embodiments, based on the determined communication path between devices **104** and **106**, the XR framework may assign particular nodes as part of a virtual connection. In some embodiments, the XR framework may generate a virtual connection communicatively coupling the first and second user devices based on determining the third communication path. In embodiments where a group of virtually proximate devices is interconnected, the XR framework may form a virtual network comprising a plurality of virtual connections between devices. For example, the XR framework may assign one or more intermediate nodes as dedicated servers for the virtual network and have externally linked devices transmit data between devices through a particular path of the virtual network.

[0045] In one example, the device **104** may transmit an indication that the device **116** (e.g., a Bluetooth speaker) is shareable to other avatars in the VE **130**. Based on the indication, the XR framework **102** may generate advertising and discovery services of the device **116** in the VE **130** and/or generate an interactive representation or digital twin of the device **116** (e.g., model **136**). As an example, the XR framework **102** may generate a virtual user interface in the VE that lists the discoverable devices. The device **106** may virtually pair and/or connect with the Bluetooth speaker, for example, by selecting a status indicator **158** corresponding to the device **116** in the virtual user interface through the avatar **146**. The XR framework **102** generates the instructions for device information exchange and establishes a communication path, or virtual bridge, for pairing and connecting the device **116** and the device **106**. For example, the device **106**, via the virtual bridge, may receive pairing information similar to the pairing information stored at the device **104** for the device **116**. In some embodiments, the XR framework **102** may access the device information stored at the device **104** for the device **116** (e.g., pairing information). Based on the stored device information, the XR framework **102** may generate and/or transmit the relevant device information for the device **106** to pair and/or connect with the device **116** via the virtual bridge. For example, the device information may include a local IP address for the device **116** that is accessible for the device **104** due to physical proximity and would not be accessible for the device **106**. The XR framework **102** may generate a modified address based on the IP address or other device information, where the modified address is accessible for the device **106** via the virtual bridge. In some embodiments, the XR framework may spawn a virtual network that extends the communication path between the device **116** and the device **104** to include the device **106**. The XR framework may generate device/connection information (e.g., device addresses, network addresses, etc.) for the devices in the virtual network. In this manner and others described herein, the virtual bridge communicatively couples the device **116**, the device **104**, and the device **106**.

[0046] In some embodiments, the XR framework **102** generates a virtual device (e.g., a digital twin of the device **116**) by replicating the various protocol advertising packets, metadata, and other protocol information as a digital representation. The replicated data may be referred to as virtualized data packets. As described herein, a physical device refers to a device at a geographical location (e.g., device **112**) and a virtual device refers to a digital representation of a device in a virtual environment (e.g., model **132**). Additionally, or alternatively, if the physical device is a content-rendering system (e.g., a Bluetooth speaker, a video decoder, etc.), the XR framework **102** may expose the components (e.g., decoder, codecs, audio output, etc.) of the system as a virtual rendering system. In some embodiments, the XR framework **102** generates virtualized components for the virtual device based on information about the physical device (e.g., specifications, components, a 3D model, etc.). For example, the XR framework **102** may receive a request from one or more XR devices for a first XR device to share a physical device. The first XR device may indicate an acceptance of the request. Based on the indication from the first XR device, the XR framework **102** may generate a virtual device that includes capabilities mirroring the physical device (e.g., music playback, volume control, etc.).

[0047] In some embodiments, the XR framework **102** receives various data packets (e.g., RF advertisement packets, RF protocol packets, etc.). The XR framework **102** may convert the data packets to virtualized data packets for transmitting via a virtual bridge and vice versa. The XR framework **102** may apply a ray tracing technique for determining a position in the VE **130** that would be within a broadcast range of virtualized data packets from a virtual device. As an example, in a VE (e.g., in a metaverse-type environment), a first virtual avatar (e.g., avatar **144**) moves into a range or a predefined virtual proximity threshold (e.g., space **140**, based on the VE's coordinate system, collision detection, etc.) to a second virtual avatar (e.g., avatar **146**). The XR framework **102** may transmit virtualized data packets from a content-rendering system to the device corresponding to the second avatar (e.g., device **106**) via a virtual bridge. Alternatively, the XR framework **102** may pair a physical device connected to the device corresponding to the second avatar with a virtual device via the virtual bridge. As an example, the XR framework **102** may receive selection of an option for pairing a virtual device (e.g., a digital twin of a physical device including a radio, a mobile phone, an XR headset, etc.) and a physical device (e.g., a mobile phone, a playback system, etc.). The XR framework **102** may convert virtualized data packets from the virtual device to data packets suitable for the physical device. In one instance, the XR framework **102** may instruct an XR device (e.g., device **104**) to broadcast the converted data packets.

[0048] In some embodiments, the XR framework **102** may modify output characteristics (e.g., audio output characteristics, haptic feedback, etc.) based on positioning of virtual representations in a VE. For example, audio output characteristics may include an audio output volume, audio effects, etc. For example, speech volume between avatars **144** and **146** may be increased or decreased based on the distance between positions of the avatars in the VE **130**. For example, the model **136** (e.g., a virtual speaker) may be closer to avatar **146** than avatar **144** in the VE **130**. The model **136** may be outputting music or other audio content. The XR framework **102** may modify the music by adjusting the volume level, adding audio effects (e.g., echo), include synthesized audio, etc. The XR framework **102** may generate a first modified audio for user device **104** and a second modified audio for user device **106**. In this instance, the first and second modified audio may have been altered to reflect the acoustic difference based on distance of the avatars **144**, **146** from the model **136**. For example, the first modified audio may have a reduced volume relative to the second modified audio.

[0049] FIG. **2** shows an example scenario **200** of an XR framework **202** linking a device **204** associated with a virtual representation at a virtual event **212** in a virtual environment **210** with a group of virtually proximate devices **205-207**, in accordance with some embodiments of this disclosure. In the scenario **200**, the XR framework **202** may be connected to four XR devices **204-207** (labeled XR1-XR4). For example, the XR framework **202** may be communicatively coupled to device **204** via a communication path **230**. Each of XR devices **204-207** may be respectively associated with virtual representations such as avatars **214**, **225-227**. The XR framework **202** may include a virtual connection **216** that connects the devices **204-207** based on their respective avatars. The device **207** may be connected to an external device **232** via an external link **234** (e.g., via a local network). In the scenario **200**, the devices **205-207** may be virtually proximate due to accessing a virtual space **220** via their respective avatars **225-227**. The device **204** may exchange communication protocols with the virtual space **220** and/or one or more of the devices **205-207**. The XR framework **202**, based on the protocol exchange, establishes a virtual connection **216** between the device **204** and/or one or more of the devices **205-207** in the virtual space **220**. In this manner, the device **204** may be considered virtually proximate to the devices **205-207** while the associated avatar **214** is located in a space different from the virtual space **220**. The XR framework **202** may maintain the virtual connection **216** based on the exchanged communication protocols.

[0050] The VE **210** may include the virtual event **212** (e.g., a virtual concert). In some instances, the VE **210** illustrates display of the virtual event **212** based on a viewpoint of the avatar **214** as an output **218** for display at the device **204**. In the scenario **200**, the avatar **214** may be attending the virtual event **212**. The XR framework **202** may generate various content as part of the virtual event **212** (e.g., lights, music, visual effects, virtual devices, user avatars, haptic feedback, etc.). The device **204** may view the virtual event **212** as an output **218** through the viewpoint of avatar **214**. The device **204** may include a haptic feedback engine for reproducing an immersive experience as experienced through avatar **214** (e.g., replicating the bass vibration or crowd interactions at a virtual rock concert via device haptics). The XR framework **202** may receive selection of an option (e.g., via the device **204**) to share the output **218** with devices **205-207**. In some instances, one or more of the devices **205-207** may transmit a request for accessing the content from the virtual event **212**, and the device **204** may indicate acceptance of the request. The XR framework **202** may identify the virtual connection **216** for transmitting content of the virtual event **212**. The XR framework **202** may transmit the content via the virtual connection **216** to the devices **205-207** and/or the avatars **225-227**. For example, the XR framework **202** may generate a floating overlay in the virtual space **220** that displays the virtual event **212** for viewing by the avatars **225-227**.

[0051] In some embodiments, the XR framework **202** may generate one or more virtual connections for parallel transmission of different content portions of a content item (e.g., based on characteristics including content types, packet sizes, video, audio, interactions, etc.). In such embodiments, the XR framework **202** may transmit an instruction and/or associated information for combining the content portions and/or generating the content for presentation at the devices **205-207**. For example, the XR framework **202** may generate a first virtual bridge for video content and a second virtual bridge for audio content. In this example, the first virtual bridge may include a first intermediate node configured for multicasting. Similarly, the second virtual bridge may include a second intermediate node configured for multicasting. In some instances, the XR framework **202**, when generating the virtual bridges, may configure the first and second intermediate nodes to exclusively multicast to the devices **205-207** while the virtual bridges and/or the content transmission are active. In some instances, the intermediate nodes may generate the content for output based on the instructions from the XR framework **202** prior to transmitting through the last path segment to one or more of the devices **205-207**. In some instances, the devices **205-207** may generate the content for output during receipt of the transmission based on the instructions from the XR framework **202**.

[0052] In some embodiments, the XR framework **202** identifies at least one intermediate node for each of the plurality of user devices (e.g., devices **205-207**) and generates a virtual connection for each user device that includes the corresponding intermediate node. For example, the XR framework **202** may identify an edge server having improved transmission qualities for device **205** but may not be suitable for transmission to device **207**. The XR framework **202** may generate a virtual bridge to device **205** that includes the edge server and generate another virtual bridge for device **207** that indicates a different communication path.

[0053] In some embodiments, a virtual representation of a first user device may be a virtual broadcasting device. For example, the avatar **214** of the XR device **204** may be configured to perform the broadcasting functions of a virtual radio (e.g., based on user settings for the avatar **214**). In this example, the avatar **214** may be configured for broadcasting within the VE **210** and for being perceived in a similar manner as an audio broadcast (e.g., a speaker system). In some embodiments, a second user device (e.g., device **205**) may transmit a request to connect to the virtual broadcasting device. Additionally, or alternatively, an avatar (e.g., avatar **225**) associated with the second XR device may be within a reception range of the virtual broadcasting device (e.g., via the virtual connection **216**). The second XR device may receive content and/or associated data via a virtual connection of the XR framework **202**. For example, the XR framework **202** may detect the avatar **225** in the VE **210** is within an audible range of a broadcast from the avatar **214** acting as a virtual radio. In response, the XR framework **202** may transmit the broadcast to the device **205** via the virtual connection **216**. Alternatively, the XR framework **202** may generate another virtual connection (not shown) that communicatively couples the virtual radio and the device **205**, allowing the broadcast in the VE **210** to be received at the device **205**.

[0054] In some embodiments, the virtual connection **216** enables routing of content from a virtual device to a physical device (e.g., device **232**) externally linked to a user device (e.g., device **207**). For example, an avatar **214** of the XR device **204** may approach a virtual building (e.g., cathedral, mosque, concert hall, location of event **212**, etc.) in the VE **210**. A virtual bridge of the XR framework **202** may allow the device **207** to receive the sounds from the virtual building (e.g., bells, sounds at event **212**) for playing on a home speaker system (e.g., device **232**) externally connected to the device **207**. In some embodiments, a group of virtual representation (e.g., avatars **214**, **225-227**) may access the same virtual space **220** for a shared activity in the virtual space **220** (e.g., an audio listening party). For example, the XR framework **202** may assign a primary role for the avatar **214** to provide music to the virtual space **220**. The group of avatars **225-227**, and their corresponding devices **205-207**, receive the music. Each of devices **205-207** may play the music via their respective media devices (e.g., device **232** for device **207**).

[0055] In some embodiments, the XR framework **202** may selectively transmit one or more content items between a plurality of devices, including physical and/or virtual devices, via a virtual connection. For example, the XR framework **202** may receive content from user equipment externally linked to a first user device via a virtual bridge. The received content may be presented at a virtual device in a VE, at one or more virtually proximate devices, and/or at one or more virtually paired physical devices. The XR framework **202** may determine which output devices based on a selection of one or more devices for presenting the received content. In one instance, the first user device may select a virtual device in a VE and/or a second user device as the output device(s). In some embodiments, the XR framework **202** may determine one or more output devices for presenting the content based on virtual proximity of their respective virtual representations in the VE. In one instance, the XR framework **202** may determine that a virtual device and a second user device are virtually proximate to a first user device and cause the content to be outputted at the virtual device and the second user device. It is contemplated that there may be multiple configurations available for selectively sharing content via a virtual connection, and the examples described herein are intended to be illustrative and non-limiting. The following paragraph describes one non-limiting example.

[0056] As an illustrative example, the XR framework **202** may generate a virtualized audio playback system, or virtual system, in a VE **210**. A smartphone may be virtually proximate to the virtual system. The smartphone may be externally linked to a smart home system. An XR headset may be connected to the smartphone via a virtual connection of the XR framework **202**. A podcast may be presented from the virtual system as a broadcast in the VE. A movie may be transmitted to the VE via the XR headset. In some instances, the movie may be generated for display (e.g., as video frames, segments, etc.) at the XR headset, at user equipment (e.g., a home theater system, set-top box, etc.), and/or another content provider system. The movie, or portions thereof, may be generated for display prior to transmitting the movie to the XR framework **202**. The XR framework **202** may determine that the smartphone, or an avatar thereof, is within range to receive the podcast in the VE **210** (e.g., the avatar is within listening range of the VE broadcast). The XR framework **202** may transmit the podcast and the movie to the smartphone. The XR headset may select the smartphone as an output device for presenting the movie. The smartphone may select the smart home system as an output device for presenting the podcast. The XR framework **202**, based on these selections, may transmit instructions to the corresponding devices. The instructions may be configured to cause the movie to be outputted at the smartphone and cause the podcast to be outputted at the smart home system (e.g., at speakers of the smart home system). As another example with a similar configuration, the first user device may be a first XR headset and the second user device may be a second XR headset. The second XR headset may transmit user audio captured by a microphone of the second headset. For example, the user audio may include user speech during online social events such as a gaming session, a video conference, a metaverse-based gathering, etc. Background sounds (e.g., ambience, background music, etc.) may be coming from the VE **210** (e.g., as heard by avatars within the VE). The XR framework **202** may determine that the first XR headset corresponds to the user audio and that the smart home system corresponds to the background sounds. In this instance, the XR framework **202** may selectively transmit, via a virtual connection, the user audio for output at the first XR headset and the background sounds for output at the smart home system.

[0057] It is noted that the scenarios **100**, **200** are intended to be illustrative and non-limiting. An XR framework as described herein may provide connectivity through proxying virtually proximate devices in various situations. Some illustrative, non-limiting examples are described as follows. For example, a first user device (e.g., a smartphone, an XR headset, etc.) could be paired with a Bluetooth speaker outside a Bluetooth connectivity range through a virtually proximate second user device externally connected to the Bluetooth speaker. A virtual bridge may be generated as an optimized communication path between the first user device and the Bluetooth speaker, enabling the first user device to play music from the speaker through audio output components of the first user device and/or broadcast to linked devices (e.g., a smart home speaker system). In a second example, a device in a group of virtually proximate devices may enable a discoverable mode for an externally linked device through a virtual bridge. The externally linked device may be paired to the device group in the VE, enabling synchronized delivery of content to the group, e.g., for replicating the video and/or audio of an MR concert attended by one or more digital avatars of the group of devices. As a third example, an avatar controlled via a user device could access a virtual space (e.g., modeled after a café). The user device may stream the sights, sounds, and ambience of the virtual space (e.g., the music playing in the background of the virtual café). Based on a device or application configuration, a user device may continue streaming content received from the virtual space via a virtual bridge while the avatar is idle in the virtual space, e.g., for playing the background music.

[0058] FIG. **3** shows an illustrative system **300** for consuming content (e.g., XR content), in accordance with some embodiments of this disclosure. System **300** may include components for generating and providing XR content (e.g., encoder, decoder, network components, content delivery networks (CDN), etc.). System **300** may comprise media content source **302**, one or more servers **330**, and one or more edge servers **340** (e.g., included as part of an edge computing system). System **300** may comprise user equipment devices **320** (e.g., devices **321-324**) and/or any other suitable number and types of user equipment capable of transmitting data by way of communication network **310**.

[0059] Media content source **302**, server **330** or edge server **340**, or any combination thereof, may include one or more content processing devices (e.g., an encoder, graphics processing devices, etc.). The content processing devices may comprise any suitable combination of hardware and/or software configured to process data to reduce storage space required to store the data and/or bandwidth required to transmit the image data, while minimizing the impact on the quality of the content being processed. In some embodiments, the data may comprise raw, uncompressed extended reality (3D and/or 4D) media content, or extended reality (3D and/or 4D) media content in any other suitable format. In some embodiments, each of user equipment devices **320** may receive processed data locally or over a communication network (e.g., communication network **310**). In some instances, the devices **320** may comprise one or more converters (e.g., a decoder). Such a converter may comprise any suitable combination of hardware and/or software configured to convert received data to a form that is usable as video signals and/or audio signals or any other suitable type of data signal, or any combination thereof. User equipment devices **320** may be provided with processed data and may be configured to implement one or more machine learning models to obtain an identifier of an element in a data structure and/or render a color for a particular voxel based on the identified element. In some embodiments, at least a portion of processing may be performed remote from any of the user equipment devices **320**.

[0060] User equipment devices **320** may include an illustrative head-mounted display or any other suitable XR device capable of providing XR content for user consumption. Each of the user equipment devices **320** may access, transmit, receive, and/or retrieve content and data via one or more I/O paths coupled to the respective equipment using corresponding circuitry. As an illustrative example based on the device **321**, a path to/from the communication network **310** may provide content (e.g., broadcast programming, on-demand programming, Internet content, content available over a local area network (LAN) or wide area network (WAN), and/or other content) and data to control circuitry and/or communication circuitry of the device **321**. In some embodiments, control circuitry of the device **321** may be used to send and receive commands, requests, and other suitable data using the path to/from the communication network **310** and the communication circuitry of the device **321**. Such a path may communicatively couple control circuitry of the device **321** to one or more other communication paths. I/O functions may be provided by one or more of these communication paths but may be shown as a single path to avoid overcomplicating the drawing. One or more of the user equipment devices **320** may include or be coupled to a display device **325**. In some embodiments, the display device **325** may comprise an optical system of one or more optical elements such as a lens in front of an eye of a user, one or more waveguides, or an electro-sensitive plane. For example, the user equipment devices **320** may include an illustrative head-mounted display or any other suitable XR device capable of providing XR content for user consumption and is further described with respect to FIG. **4**.

[0061] In some embodiments, an application of an XR framework may be executed at one or more of control circuitry **331** of server **330** (and/or control circuitry of user equipment devices **320** and/or control circuitry **341** of edge servers **340**). As referred to herein, control circuitry should be understood to mean circuitry based on one or more microprocessors, microcontrollers, digital signal processors, programmable logic devices, field-programmable gate arrays (FPGAs), application-specific integrated circuits (ASICs), etc., and may include a multi-core processor (e.g., dual-core, quad-core, hexa-core, or any suitable number of cores) or supercomputer. Any device, equipment, etc. described herein may comprise control circuitry. The server **330** may be coupled to a database **334**. In some embodiments, one or more data structures discussed herein may be stored at the database **334**. The data structures may be maintained at or otherwise associated with server **330**, and/or at storage **333** and/or at storage of one or more of user equipment devices **320**. Communication network **310** may comprise one or more networks including the Internet, a mobile phone network, a mobile voice or data network (e.g., a 5G, 4G, or LTE network), cable network, public switched telephone network, or other types of communication network or combinations of communication networks. Paths (e.g., depicted as arrows connecting the respective devices to the communication network **310**) may separately or together include one or more communication paths, such as a satellite path, a fiber-optic path, a cable path, a path that supports Internet communications (e.g., IPTV), free-space connections (e.g., for broadcast or other wireless signals), or any other suitable wired or wireless communication path or combination of such paths. Communications with the client devices may be provided by one or more of these communication paths but may be shown as a single path to avoid overcomplicating the drawing. Although communication paths may not be shown between user equipment devices, the devices may communicate directly with each other via one or more communication paths as well as other short-range, point-to-point communication paths, such as USB cables, IEEE 1394 cables, wireless paths (e.g., Bluetooth, infrared, IEEE 802-11x, etc.), or other short-range communication via wired or wireless paths. The user equipment devices may also communicate with each other directly through an indirect path via communication network **310**.

[0062] In some embodiments, an XR framework may include a client/server application where only the client application resides on one or more user equipment devices **320**, and a server application resides on an external server. For example, an XR framework may be implemented partially as a client application on control circuitry of a user equipment device **323** and partially on server **330** as a server application running on control circuitry **331**. Server **330** may be a part of a local area network or may be part of a cloud computing environment accessed via the Internet. In a cloud computing environment, various types of computing services for performing searches on the Internet or informational databases, generating virtualized components, providing encoding/decoding capabilities, providing storage (e.g., for a database), or processing and parsing data (e.g., using machine learning algorithms described above and below) are provided by a collection of network-accessible computing and storage resources (e.g., server **330** and/or edge server **340**), referred to as “the cloud.” For example, user equipment devices **320** may include a cloud client that relies on the cloud computing capabilities from server **330** to receive and process data for XR content. When executed by control circuitry of server **330** or **340**, an XR framework, or parts thereof, may instruct control circuitry **331** or **341** to perform processing tasks for user equipment devices **320** and facilitate execution of the various processes.

[0063] In some embodiments, server **330** may include control circuitry **331** and storage **333** (e.g., RAM, ROM, hard disk, removable disk, etc.). Storage **333** may store one or more databases. Server **330** may also include an input/output (I/O) path **332**. I/O path **332** may provide protocol exchange data, device information, or other data, over a local area network (LAN) or wide area network (WAN), and/or other content and data to control circuitry **331**, which may include processing circuitry, and storage **333**. Control circuitry **331** may be used to send and receive commands, requests, and other suitable data using I/O path **332**, which may comprise I/O circuitry. I/O path **332** may connect control circuitry **331** to one or more communication paths.

[0064] Edge computing server **340** may comprise control circuitry **341**, I/O path **342** and storage **343**, which may be implemented in a similar manner as control circuitry **331**, I/O path **332** and storage **333**, respectively, of server **330**. Edge server **340** may be configured to be in communication with one or more of user equipment devices **320** (e.g., devices **321-324**) and/or a video server (e.g., server **330**) over communication network **310** and may be configured to perform processing tasks (e.g., encoding/decoding) in connection with ongoing processing of video data. In some embodiments, a plurality of edge servers **340** may be strategically located at various geographic locations and may be mobile edge servers configured to provide processing support for mobile devices at various geographical regions.

[0065] Control circuitry **331**, **341** may be based on any suitable control circuitry. As referred to herein, control circuitry should be understood to mean circuitry based on one or more microprocessors, microcontrollers, digital signal processors, programmable logic devices, field-programmable gate arrays (FPGAs), application-specific integrated circuits (ASICs), etc., and may include a multi-core processor (e.g., dual-core, quad-core, hexa-core, or any suitable number of cores) or supercomputer. In some embodiments, control circuitry **331**, **341** may be distributed across multiple separate processors or processing units, for example, multiple of the same type of processing units (e.g., two Intel Core i7 processors) or multiple different processors (e.g., an Intel Core i5 processor and an Intel Core i7 processor). In some embodiments, control circuitry **331**, **341** executes instructions for an emulation system application stored in memory (e.g., the storage **333**, **343**). Although not shown, memory may be an electronic storage device provided as storage **333**, **343** that is part of respective control circuitry **331**, **341**.

[0066] FIG. **4** shows illustrative user equipment for consuming XR content including example XR user equipment **400**, in accordance with some embodiments of this disclosure. Equipment **400** may depict an illustrative head-mounted display or any other suitable XR device capable of providing XR content for user consumption. Equipment **400** comprises display **402**, control circuitry **404** comprising processor **406** and memory **408**, input/output (I/O) path **410**, and power source **412**. Equipment **400** may comprise one or more of integrated audio I/O components **414** and/or camera **416**.

[0067] Equipment **420** may depict a generalized embodiment of device components that correspond to parts of equipment **400** and/or are coupled to equipment **400**. In some embodiments, equipment **400** may be stand-alone or communicatively coupled to a system hub **422**. For example, hub **422** may be a set-top box or a gaming console. Any suitable computing device having processing circuitry, control circuitry, and storage may be used in accordance with the present disclosure. For example, hub **422** may include, or be complemented by, a personal computer (e.g., a notebook, a laptop, a desktop), a smartphone, a tablet, a network-based server hosting a user-accessible client device, a non-user-owned device, any other suitable device, or any combination thereof. Equipment **400** may be coupled to external user devices and/or equipment via the hub **422**. For example, the hub **422** may be coupled to external audio equipment (e.g., integrated audio I/O components **414** including speakers, headphones, and/or microphone) and/or camera **416** for supplementing the integrated components of equipment **400**.

[0068] Each of the user equipment **400** and **420** may access, transmit, receive, and/or retrieve content and data via one or more I/O paths coupled to the respective equipment using corresponding circuitry. As an illustrative example based on equipment **400**, I/O path **410** may provide content (e.g., broadcast programming, on-demand programming, Internet content, content available over a local area network (LAN) or wide area network (WAN), and/or other content) and data to control circuitry **404**. Control circuitry **404** may be used to send and receive commands, requests, and other suitable data using I/O path **410** and the communication circuitry. I/O path **410** may communicatively couple control circuitry **404** to one or more communication paths. I/O functions may be provided by one or more of these communication paths but may be shown as a single path to avoid overcomplicating the drawing.

[0069] Display **402** may depict a generalized embodiment of display device **325**. Display **402** may comprise an optical system of one or more optical elements such as a lens in front of an eye of a user, one or more waveguides, or an electro-sensitive plane. The display **402** comprises an image source providing an image beam to the optical element. The image beam may be modified (e.g., diffracted) using one or more elements of the optical system. For example, a 3D image may be displayed as output of the optical system in front of the eye of the user at the lens. The display **402** may be a 3D display. Some non-limiting examples of a display include a tensor display, a light field display, a volumetric display, a multi-layer display, an LCD display, amorphous silicon display, low-temperature polysilicon display, electronic ink display, electrophoretic display, active matrix display, electro-wetting display, electro-fluidic display, cathode ray tube display, light-emitting diode display, electroluminescent display, plasma display panel, high-performance addressing display, thin-film transistor display, organic light-emitting diode display, surface-conduction electron-emitter display (SED), laser television, carbon nanotubes, quantum dot display, interferometric modulator display, or any other suitable equipment for displaying XR content.

[0070] Control circuitry **404** may be based on any suitable control circuitry. Control circuitry **404** may comprise processor **406** and/or memory **408**. Processor **406** may include video processing circuitry (e.g., integrated and/or a discrete graphics processor). In some embodiments, control circuitry **404** may be distributed across multiple separate processors or processing units, for example, multiple of the same type of processing units (e.g., two Intel Core i7 processors) or multiple different processors (e.g., an Intel Core i5 processor and an Intel Core i7 processor). In some embodiments, control circuitry **404** executes instructions for an XR framework, or parts thereof, stored in memory (e.g., memory **408**). Specifically, control circuitry **404** may be instructed by an XR framework, or parts thereof, to perform any of the functions described herein. In some implementations, processing or actions performed by control circuitry **404** may be based on instructions received from an XR framework or parts thereof. Control circuitry **404** may be configured to generate one or more images for display via the equipment **400** and instruct the optical system to produce one or more image beams corresponding to the one or more images at display **402**.

[0071] Control circuitry **404** may be based on any suitable control circuitry. Control circuitry **404** may comprise processor **406** and/or memory **408**. As referred to herein, control circuitry should be understood to mean circuitry based on one or more microprocessors, microcontrollers, digital signal processors, programmable logic devices, field-programmable gate arrays (FPGAs), application-specific integrated circuits (ASICs), etc., and may include a multi-core processor (e.g., dual-core, quad-core, hexa-core, or any suitable number of cores) or supercomputer. Processor **406** may include video processing circuitry (e.g., integrated and/or a discrete graphics processor). In some embodiments, control circuitry **404** may be distributed across multiple separate processors or processing units, for example, multiple of the same type of processing units (e.g., two Intel Core i7 processors) or multiple different processors (e.g., an Intel Core i5 processor and an Intel Core i7 processor). In some embodiments, control circuitry **404** executes instructions for an XR framework, or parts thereof, stored in memory (e.g., memory **408**). Specifically, control circuitry **404** may be instructed by an XR framework, or parts thereof, to perform any of the functions described herein. In some implementations, processing or actions performed by control circuitry **404** may be based on instructions received from an XR framework or parts thereof. Control circuitry **404** may be configured to generate one or more images for display via the equipment **400** and instruct the optical system to produce one or more image beams corresponding to the one or more images at display **402**.

[0072] Control circuitry **404** may include or be communicatively coupled to video generating circuitry and tuning circuitry, such as one or more analog tuners, one or more H.265 decoders or any other suitable digital decoding circuitry, high-definition tuners, or any other suitable tuning or video circuits or combinations of such circuits. Conversion circuitry (e.g., for converting over-the-air, analog, or digital signals to MPEG signals for storage) may also be provided. Control circuitry **404** may also include scaler circuitry for upconverting and downconverting content into a suitable output format of user equipment **400**. Control circuitry **404** may also include or be communicatively coupled to digital-to-analog converter circuitry and analog-to-digital converter circuitry for converting between digital and analog signals. The tuning and generating circuitry may be used by user equipment **400** to receive and to display, to play, or to record content. The tuning and generating circuitry may also be used to receive video generating data. The circuitry described herein, including, for example, the tuning, video generating, encoding, decoding, encrypting, decrypting, scaler, and analog/digital circuitry, may be implemented using software running on one or more general purpose or specialized processors. Multiple tuners may be provided to handle simultaneous tuning functions (e.g., watch and record functions, picture-in-picture (PIP) functions, multiple-tuner recording, etc.). If memory **408** is provided or supplemented by a separate device from user equipment **400**, the tuning and generating circuitry (including multiple tuners) may be associated with memory **408**.

[0073] Memory **408** may be any device for storing electronic data, such as random-access memory, solid state devices, quantum storage devices, hard disk drives, non-volatile memory or any other suitable fixed or removable storage devices, and/or any combination of the same. Memory may be an electronic storage device that is part of control circuitry **404**. As referred to herein, the phrase “electronic storage device” or “storage device” should be understood to mean any device for storing electronic data, computer software, or firmware, such as random-access memory, read-only memory, hard drives, optical drives, digital video disc (DVD) recorders, compact disc (CD) recorders, BLU-RAY disc (BD) recorders, BLU-RAY 3D disc recorders, digital video recorders (DVR, sometimes called a personal video recorder, or PVR), solid state devices, quantum storage devices, gaming consoles, gaming media, or any other suitable fixed or removable storage devices, and/or any combination of the same. Memory **408** may store data defining images for display by the head-mounted display. Memory **408** may be used to store various types of content described herein including XR asset data. Nonvolatile memory may also be used (e.g., to launch a boot-up routine and other instructions). Cloud-based storage may be used to supplement memory **408** or instead of memory **408**.

[0074] Control circuitry **404** may include or be coupled to communication circuitry suitable for communicating with a server, edge computing systems and devices, a table or database server, or other networks or servers. The instructions for carrying out the above-mentioned functionality may be stored on a server. Such communications may involve the Internet or any other suitable communication networks or paths. In addition, communication circuitry may include circuitry that enables peer-to-peer communication of user equipment devices, or communication of user equipment devices in locations remote from each other. In some embodiments, I/O path **410** comprises circuitry that communicatively couples the head-mounted display to one or more other devices over a network. For example, I/O path **410** may include a network adaptor and associated circuitry. I/O path **410** may comprise wires and/or busses for connecting to a physical network port (e.g., an ethernet port, a wireless WiFi port, cellular communication port, or any other type of suitable physical port). Although communication paths are not shown between user equipment devices, any of the described devices and equipment may communicate directly or indirectly with each other via one or more communication paths and/or communication networks including short-range, point-to-point communication paths, such as USB cables, IEEE 1394 cables, wireless paths (e.g., Bluetooth, infrared, IEEE 802-11x, etc.), or other short-range communication via wired or wireless paths. For example, I/O **410** may include a Bluetooth network adaptor.

[0075] Power source **412** comprises a source of power or the interfaces for coupling a power source to the display **402**, control circuitry **404**, memory **408**, and/or I/O path **410**. While not shown, power source **412** may be coupled to other components of equipment **400**. Some non-limiting examples of a power source include a battery, solar generator, and/or a wired power source.

[0076] Audio I/O equipment **414** may be provided as integrated with other elements of each one of equipment **400**, **420** or may be stand-alone units. An audio component of videos and other content may be played through speakers (or headphones) of audio I/O equipment **414**. In some embodiments, audio may be distributed to a receiver (not shown), which processes and outputs the audio via speakers of audio I/O equipment **414**. In some embodiments, for example, control circuitry **404** is configured to provide audio cues to a user, or other audio feedback to a user, using speakers of audio output equipment **414**. There may be a separate microphone and/or audio I/O equipment **414** may include a microphone configured to receive audio input such as voice commands or speech. For example, a user may speak letters or words that are received by the microphone and converted to text by control circuitry **404**. As a second example, a user may voice commands that are received by a microphone and recognized by control circuitry **404**. Camera **416** may be any suitable video camera integrated with the equipment or externally connected (e.g., via hub **422**). Camera **416** may be a digital camera comprising a charge-coupled device (CCD) and/or a complementary metal-oxide semiconductor (CMOS) image sensor. Camera **416** may be an analog camera that converts to digital images via a video card.

[0077] In some embodiments, equipment **400** and/or equipment **420** may be communicatively coupled to one or more user input interfaces or devices **418**. Some examples of input devices include a remote control, a secondary user device, a touch-sensitive display, a smartphone device, a tablet, a remote control, mouse, trackball, keypad, keyboard, touchscreen, touchpad, stylus input, joystick, voice recognition interface, and/or other user input interfaces. In some embodiments, equipment **400** comprises an integrated user input interface capable of tracking a user's eyes and/or detecting visual and/or audio cues. Equipment **400** may include one or more interface regions for a user to manipulate (e.g., buttons, touch-sensitive bars, etc.). As an example, input interface **418** may include a handheld remote-control device having a microphone and control circuitry configured to receive and identify voice commands and transmit information to equipment **400** directly or via equipment **420**.

[0078] An XR framework, or parts thereof, may be implemented using any suitable architecture. For example, it may be a stand-alone application wholly implemented on any of user equipment **400**, **420**. Instructions of the application may be stored locally (e.g., in memory **408**), and data for use by the application is downloaded on a periodic basis (e.g., from an out-of-band feed, from an Internet resource, or using another suitable approach). Control circuitry **404** may retrieve instructions of the application from memory **408** and process the instructions to provide networking functionality and perform any of the actions described herein. Based on the processed instructions, control circuitry **404** may determine what action to perform when user input is received. For example, movement of a cursor on a display up/down may be indicated by the processed instructions when input interface **418** indicates that an up/down button was selected.

[0079] In some embodiments, an XR framework, or parts thereof, includes a client/server-based application. In client/server-based embodiments, control circuitry **404** may include or be coupled to communication circuitry (e.g., I/O path **410**) suitable for communicating with a server or other networks or servers. An XR framework, or parts thereof, may be a stand-alone application implemented on a device or a server. An XR framework, or parts thereof, may be implemented as software or a set of executable instructions. An application and/or any instructions for performing any of the embodiments discussed herein may be encoded on computer-readable media. The computer-readable media may be non-transitory, including, but not limited to, volatile and non-volatile computer memory or storage devices such as a hard disk, floppy disk, USB drive, DVD, CD, media card, register memory, processor cache, random access memory (RAM), a hard drive, random-access memory on a DRAM integrated circuit, read-only memory on a BLU-RAY disk, etc. For example, in FIG. **4**, the instructions may be stored in memory **408**, and executed by control circuitry **404** of the equipment **400**.

[0080] Data for use by a thick or thin client implemented on any one of user equipment **400**, **420** may be retrieved on demand by issuing requests to a server remote to any one of user equipment **400**, **420**. For example, the remote server may store the instructions for the application in a storage device. The remote server may process the stored instructions using circuitry (e.g., control circuitry **404**) and generate the displays discussed above and below. The client device may receive the displays generated by the remote server and may display the content of the displays locally on equipment **400**. This way, the processing of the instructions is performed remotely by the server while the resulting displays (e.g., which may include text, a keyboard, or other visuals) are provided locally on equipment **400**. Equipment **400** may receive inputs from the user via input interface **418** and transmit those inputs to the remote server for processing and generating the corresponding displays. For example, equipment **400** may transmit a communication to the remote server indicating that an up/down button was selected via input interface **418**. The remote server may process instructions in accordance with that input and generate a display of the application corresponding to the input (e.g., a display that moves a cursor up/down). The generated display is then transmitted to equipment **400** for presentation to the user.

[0081] In some embodiments, an XR framework, or parts thereof, may be downloaded and interpreted or otherwise run by an interpreter or virtual machine (run by control circuitry **404**). In some embodiments, an XR framework, or parts thereof, may be encoded in the ETV Binary Interchange Format (EBIF), received by control circuitry **404** as part of a suitable feed, and interpreted by a user agent running on control circuitry **404**. For example, an XR framework, or parts thereof, may include an EBIF application. In some embodiments, an XR framework, or parts thereof, may be defined by a series of JAVA-based files that are received and run by a local virtual machine or other suitable middleware executed by control circuitry **404**. In some of such embodiments (e.g., those employing MPEG-2 or other digital media processing schemes), an XR framework, or parts thereof, may be, for example, encoded and transmitted in an MPEG-2 object carousel with the MPEG audio and video packets of a program.

[0082] FIG. **5** is a flowchart of an example process **500** for connecting virtually proximate devices, in accordance with some embodiments of this disclosure. In various embodiments, process **500** may be executed via one or more components associated with an XR framework. For example, the process **500** may be implemented, in whole or in part, by the systems **300**, **400** at FIGS. **3-4**.

[0083] At block **502**, control circuitry associated with an XR framework, or parts thereof, may generate a virtual environment. At block **504**, the control circuitry may connect a first user device and a second user device to the VE. As an illustrative example, referring to FIG. **3**, the XR framework may include a server **330** comprising the control circuitry **331**. The server **330** may host a VE. The control circuitry **331** may receive, via the communication network **310**, requests from the user devices (e.g., user equipment **320**) to access the VE at the server **330**. Based on the requests, the control circuitry **331** transmits the relevant access information for each user device. For example, any of the user devices **321-324** may request to access the same virtual space.

[0084] At block **506**, the control circuitry may determine that the first user device and the second user device are virtually proximate, for example, based on connecting to the same virtual space in the VE. In some embodiments, the control circuitry of the XR framework may determine that the user devices have exchanged relevant information (e.g., communication protocols) for initiating a communication link via the VE. For example, referring to FIG. **3**, the user device **321** may exchange an access key with the user device **323** and vice versa. The access key may be generated via secure key exchange techniques (e.g., cryptographic, password-authenticated, etc.) via the user devices and/or the XR framework (e.g., an XR engine). At block **508**, the control circuitry may receive device information about a media device in a sharing or discoverable mode. For example, the media device may be paired with the first user device. The relevant media device information (e.g., device registration information for the media device) may be stored or is otherwise accessible at the first user device. Based on the media device status, the first user device may indicate to the XR framework (e.g., via communication network **310**) that the media device is available for sharing and/or transmit the media device information.

[0085] At block **510**, the control circuitry may cause a virtual representation of the media device to be presented in the VE. The control circuitry may generate the virtual representation based on the device information. For example, the control circuitry **331** may generate a model of the media device for display in the VE by accessing device information (e.g., device specifications) stored at the database **334** and/or via the communication network **310**. For example, the control circuitry **331** may transmit a search query to an Internet-based search engine. For example, the control circuitry **331** may access and/or identify information about the media device for generating the virtual representation of the media device (e.g., from a manufacturer and/or commerce website about the media device). In some embodiments, the control circuitry may generate a virtual broadcast in the VE indicative of the media device being available, for example, by generating a virtual broadcast device at a position or virtual space in the VE.

[0086] At block **512**, the control circuitry may receive, from the second user device, a selection of the virtual representation. For example, an avatar controlled via the second user device may interact with the virtual representation of the media device or a virtualized media device. For example, referring to FIG. **4**, a user, via user equipment **400**, may control an avatar using the input interface **418** (e.g., using a controller, via eye tracking, etc.). In response to the avatar contacting the virtualized media device, the user equipment **400** may transmit the interaction data and/or an access request to the control circuitry **331** (e.g., received via I/O path **332**). Based on the interaction data, the control circuitry **331** may determine that the user equipment **400** has selected the virtualized media device for access. As a second example, the control circuitry **331** may determine that the avatar interacts with a particular part of the virtualized media device (e.g., a virtual on/off switch) and, based on the interaction, determine that the user equipment **400** is requesting device access.

[0087] At block **514**, the control circuitry may generate a virtual connection between the media device, the first user device, and the second user device. For example, each user device may have a communication path to the XR framework. For example, the first user device may be connected to a first edge server (e.g., edge server **340**) and the second user device may be connected to the same edge server or a second edge server. The control circuitry may generate a virtual bridge between the communication paths to form the virtual connection (e.g., by generating a virtual bridge device between the first and second edge servers and/or nodes thereof). At block **516**, the control circuitry may transmit, via the virtual connection, media content between the media device, the first user device, and the second user device. For example, the control circuitry may redirect the media content from the media device to the second user device via the virtual connection. For example, referring to FIG. **3**, the control circuitry **331** may generate a dedicated communication path via communication network **310** that links the involved devices using the virtual bridge.

[0088] FIG. **6** is a flowchart of an example process for sharing content to virtually proximate devices, in accordance with some embodiments of this disclosure. In various embodiments, process **600** may be executed via one or more components associated with an XR framework. For example, the process **600** may be implemented, in whole or in part, by the systems **300**, **400** at FIGS. **3-4**.

[0089] At block **602**, one or more virtual representations, or avatars, are generated in a VE via control circuitry associated with an XR framework (e.g., at an XR engine). For example, control circuitry **331** may generate the avatars associated with XR devices connected to the VE. At block **604**, the virtual environment is rendered for presenting at the connected XR devices. At block **606**, the control circuitry may determine whether the XR devices are virtually proximate. For example, the control circuitry **331** may determine that the avatars are in the same virtual space of the VE. In some embodiments, the control circuitry may track the position of the avatars in the VE to determine that the avatars are within a virtual proximity of each other. In some embodiments, the control circuitry may monitor a connectivity status between avatars and their respective devices. If the XR devices are not virtually proximate (“No” at **606**), the control circuitry may continue rendering and/or updating the VE at block **604**. If the XR devices are virtually proximate (“Yes” at **606**), then the control circuitry may receive or otherwise determine (e.g., via an interaction from one or more avatars and/or between the avatars) a request to share a media device externally linked to a first device of the virtually proximate devices at block **608**.

[0090] At block **610**, the control circuitry may determine whether an external connection (e.g., a direct or local link) between virtually proximate devices is available. For example, if a direct connection via a local network is available (“Yes” at **610**), the control circuitry may leverage the direct connection to link the XR devices within the local network. In this example, the control circuitry may establish a local network connection between the XR devices. For example, if a direct connection is available between the media device and the second XR device (e.g., within Bluetooth connectivity range of each other), the control circuitry may determine to link these devices with the direct connection. At block **612**, the control circuitry may access information about the direct connection to generate the link between the devices. For example, the control circuitry may access the network addresses of the devices in the local network. At block **614**, the control circuitry establishes the external connection for sharing content from the media device, for example, by transmitting one or more instructions to the local network device (e.g., router, hub, etc.) that cause the network device to generate and transmit relevant data for the external connection (e.g., communication protocols, local routing table, forwarding rules, etc.).

[0091] At block **610**, the control circuitry may determine that an external connection is unavailable. For example, the control circuitry **331** may access positioning information (e.g., via a global positioning system (GPS)) and determine that the device **322** is geographically distant from the device **324** and thus outside a connectivity range for an external connection (e.g., a direct RF-based connection). If an external connection is unavailable ("No" at **610**), the control circuitry may access information about the involved devices and the communication paths (e.g., current connections, available nodes, etc.) for generating a virtual connection, including a virtual bridge, in the VE at block **616**. At block **618**, the control circuitry may generate the virtual connection based on the accessed information. For example, the control circuitry **331** may generate a virtualized bridge device linking nodes of the respective communication paths for the virtually proximate devices. The virtualized bridge device may be configured to detect data packets transmitted via one of the linked nodes. For example, the virtualized bridge device may identify that data packets, received from a first virtually proximate device, are addressed to a second virtually proximate device. The virtualized bridge device may automatically redirect the data packets to reach the second virtually proximate device via the virtual connection. In some embodiments, the control circuitry **331** generates a virtual network and relevant information (e.g., network addresses, etc.) that includes the virtually proximate devices and any devices externally connected to one or more of the virtually proximate devices.

[0092] Once a connection between devices is established (e.g., a local direct or virtual connection), the control circuitry may generate a virtual representation of the media device (e.g., an interactive XR object) for presenting in the VE at block **620**. At block **622**, the control circuitry may receive an interaction with the virtual representation, for example, that causes the virtual media device to present various content items. At block **624**, the control circuitry may provide the media content to one or more physical devices via the established connection such as the external connection or the virtual connection. For example, a first user device **322** may be externally connected to a home speaker system playing music content. A second user device **323** may be externally connected to a smart hub system including audio output devices. The control circuitry **331** may have established a virtual connection between the device **322** and the device **323** for providing the music content to the smart hub system. The control circuitry **331** may cause the smart hub system to play the music content by directing a stream of the music content from the home speaker system to the smart hub system via the virtual connection. The control circuitry **331** may transmit an instruction for the smart hub system to play the content stream.

[0093] At block **626**, the control circuitry may provide media content via the virtual representation of the media device (e.g., an interactive XR object such as the virtualized media device) in the VE. Continuing the prior example, the control circuitry **331** may have generated a virtual audio renderer in the VE that corresponds to the home speaker system. The control circuitry **331**, via the virtual connection, may receive a stream of the music content and play the music content in the VE through the virtual audio renderer. Process **600** may cycle between blocks **624** and **626** via feedback **628** between a physical media device and a virtual media device. For example, the feedback **628** may include a voice input at the physical media device that modifies the presented media content. The control circuitry, based on the feedback **628**, may modify the media content at the virtual media device to synchronize the presentation of the media content in the physical environment and the virtual environment.

[0094] FIG. **7** is a flowchart of an example process **700** for establishing a virtual connection between virtually proximate devices, in accordance with some embodiments of this disclosure. In various embodiments, process **700** may be executed via one or more components associated with an XR framework. For example, the process **700** may be implemented, in whole or in part, by the systems **300**, **400** at FIGS. **3-4**. Control circuitry associated with an XR framework may perform some or all of the steps described regarding the process **700**. For illustrative purposes, reference is made to control circuitry **331** in the following paragraphs. It is contemplated that capable components at any of the systems and/or devices described herein, and combinations thereof, may perform the actions of the process **700**.

[0095] At block **702**, a content renderer is paired with a first XR device (e.g., equipment **400**). At block **704**, the content renderer is selected to be shareable, for example, via the first XR device. The first XR device may receive first data packets from the content renderer. At block **706**, the first data packets are converted to a suitable format for a virtualized content renderer, or virtual device, in a VE. For example, the first XR device may receive the first data packets and device information about the content renderer. The control circuitry **331** may generate a virtual device based on the device information. The first XR device may generate virtualized data packets by demodulating the first data packets. The virtualized data packets may be transmitted to the control circuitry **331** and, in particular, to the virtual device in the VE. In some embodiments, the control circuitry **331** may receive the first data packets and generate the virtualized data packets for the virtual device.

[0096] At block **708**, the control circuitry **331** may generate a first virtual avatar associated with the first XR device. The first virtual avatar is presented in the VE. At block **710**, the control circuitry **331** may advertise the virtual device in the VE. For example, the control circuitry **331** may broadcast that the content renderer is shareable using the first virtual avatar as a transceiver in the VE. For example, the control circuitry **331** may modify a part of the virtual device as a transceiver for advertising the virtual device in the VE. At block **712**, the control circuitry **331** may determine if a second virtual avatar is near to the virtual device. If a second virtual avatar is not nearby (“No” at **712**), the control circuitry **331** may continue advertising at block **710**. For example, the control circuitry **331** may determine that no virtual avatar is within a proximity threshold of the virtual broadcast source in the VE.

[0097] In some embodiments, the XR framework may determine a broadcast range based on a connectivity parameter for the content renderer. For example, the control circuitry may determine that the device information for the content renderer indicates a reliable connectivity range parameter of 40 feet and adjusts the broadcast range in the VE to be detectable to virtual avatars/devices within a 40-foot radius, or its analogue in the VE, from the first virtual avatar and/or the virtual device. In some embodiments, the XR framework may determine a broadcast range based on a VE parameter. For example, in a metaverse-based application, a broadcast range of a virtual device may extend up to the bounds of a virtual space (e.g., a virtual convention or other event venue, video conferencing space, a breakout room, etc.). In some advantageous aspects, determining a broadcast range of a first virtual device based on parameters of a first virtual space of the VE may prevent unauthorized access or interference from a second virtual space with the first virtual device and its corresponding physical device.

[0098] If there is a second virtual avatar nearby (“Yes” at **712**), the control circuitry **331** transmits the virtualized data packets to the second XR device associated with the second avatar at block **714**. The control circuitry **331** generates a virtual connection for transmitting the virtualized data packets. In some embodiments, the control circuitry **331** generates readable data packets for the second XR device by modulating the virtualized data packets. In some embodiments, the second

XR device may convert the virtualized data packets to a suitable format for the second XR device. At block **716**, the control circuitry **331** may determine that the second XR device provides the converted data packets to one or more externally linked devices. In some instances, the second XR device may generate data packets in a readable format for the externally linked devices.

[0099] The second XR device may receive data packets from the externally linked devices (second data packets henceforth). For example, an externally linked device may receive a selection of a play option (e.g., a pause command). In response, the externally linked device may generate virtualized data packets for the second XR device. At block **718**, the second XR device receives the virtualized data packets. At block **720**, the second XR device may convert the virtualized data packets into a readable format for the first XR device. The second XR device transmits the converted data packets to the first XR device via the virtual connection. At block **722**, the first XR device receives the data packets from the second XR device and transmits the data packets to the content renderer. For example, the selected play option is provided to the content renderer. The content renderer may modify presentation of the content (e.g., pausing the presentation). The content renderer may generate a success message and content synchronization data (e.g., the paused frame, a content signature, etc.). The content renderer may transmit the success message and content synchronization data to the first XR device, for example, as feedback data. At block **724**, the control circuitry **331** may receive, from the first XR device, the data packets (e.g., the feedback data from the content renderer). Process **700** may return to block **706** based on the received data packets (e.g., to generate an updated virtual device based on the content synchronization data).

[0100] FIG. **8** is a flowchart of a detailed illustrative process **800** for connecting virtually proximate devices and sharing content between the devices, in accordance with some embodiments of this disclosure. In various embodiments, process **800** may be executed via one or more components associated with an XR framework. For example, the process **800** may be implemented, in whole or in part, by the systems **300**, **400** at FIGS. **3-4**. In some aspects, the process **800** illustrates an example data flow between media device **802**, a first user device **804**, an XR system **806**, and a second user device **808**, e.g., as described regarding the process **500**.

[0101] At **810**, the device **802** and the device **804** are linked via pairing or any other external connection. At **812-814**, the device **804** and the device **808** access the same virtual space of the XR system **806**. At **816**, based on accessing the same virtual space, the XR system **806** generates a virtual device bridge between the devices **804** and **808**. In this example, the devices **804** and **808** may be communicatively coupled by the virtual device bridge, forming a communication path between nodes of the XR system **806** and bypassing a central server of the XR system **806**. The XR system **806** may dynamically adjust the virtual device bridge, for example, by selecting the nodes as part of the communication path to maintain a stable data transmission rate between the devices **804** and **808**. At **818**, the device **804** may indicate to the virtual space of the XR system **806** that the device **802** is shareable (e.g., in a discoverable mode). The XR system **806** may receive information about the device **802** for advertising in the virtual space. At **820**, the XR system **806** may transmit the information about the device **802** to the device **808**. In this manner, the device **808** may detect that the device **802** is available. For example, the device **802** may be listed in a UI presented at the device **808** as a discoverable virtual device. At **822**, the device **808** transmits, via the virtual device bridge, a request to the device **804** for connecting to the device **802**.

[0102] At **824**, the device **804** may retrieve connection information from the device **802**, for example, in response to the connection request from the device **808**. At **826**, the device **804** and the device **808** exchange the connection information via the virtual device bridge. For example, the devices **802** and **808** may be paired via the virtual device bridge in an analogous manner as the pairing between the devices **802** and **804**. At **828**, the device **802** may transmit a content item (e.g., including video, audio, etc.) to the device **804**. At **830**, the device **804** may provide the content item to the virtual space of the XR system **806**. For example, the XR system **806** may generate a virtual device that presents the content item in the virtual space. At **832**, the device **804** may provide the content item to the device **808** via the virtual device bridge. In some embodiments, at **834**, the device **808** may transmit and/or play the content item using one or more externally linked devices. Additionally, or alternatively, at **836**, the device **808** may provide content such as a second content item (e.g., from an externally linked device) to the device **804** via the virtual device bridge. At **838**, the device **804** may play the content (e.g., the second content item) using the device **802** or another externally connected device.

[0103] In various embodiments, the individual steps of processes **500-800** may be implemented by one or more components of the devices and systems described with respect to FIGS. **1-4**. For example, the processes **500-800** may be implemented, in whole or in part, by the one or more components of systems **100-400**. While certain steps of the processes **500-800** and other processes are described herein as being implemented by certain components and/or devices, it is noted that this is for illustrative purposes, and it is understood that other suitable device and/or system components may be substituted without departing from the teachings of the present disclosure.

[0104] The systems and processes described herein are intended to be illustrative and not limiting. One skilled in the art would appreciate that the system components and/or steps of the processes discussed herein may be suitably substituted, omitted, modified, combined and/or rearranged. Components and/or steps may be added without departing from the scope of the present disclosure. More generally, the above disclosure is meant to be illustrative and not limiting. Only the claims that follow are meant to set bounds as to what the present disclosure includes. Furthermore, it should be noted that the features described in any one embodiment may be applied to any other embodiment herein, and flowcharts or examples relating to one embodiment may be combined with any other embodiment in a suitable manner, done in different orders, or done in parallel. In addition, the systems and methods described herein may be performed in real time. It should also be noted that the systems and/or methods described above may be applied to, or used in accordance with, other systems and/or methods.

Claims

1. (canceled)

2. A method comprising: generating, for display in a virtual space, a virtual representation of a media device, wherein the media device is externally connected to a first device, and wherein the first device is connected to the virtual space; receiving, via the virtual representation displayed in the virtual space, a selection corresponding to the media device; and establishing, based on connectivity information between the first device and the virtual space, a virtual connection for providing media content from the media device to one or more other devices connected to the virtual space.

3. The method of claim 2, wherein generating the virtual connection comprises generating a virtual bridge for joining respective communication paths between the first device and the one or more other devices via the virtual space.

4. The method of claim 2, further comprising generating a respective virtual connection between the media device and each device of the one or more other devices, wherein the media content is transmitted to the each device via the respective virtual connection.

5. The method of claim 2, wherein the first device is externally connected to the media device via a local network.

6. The method of claim 2, wherein the first device is an extended reality (XR) wearable device.

7. The method of claim 2, further comprising: generating, for display in the virtual space, a user interface (UI) comprising one or more options corresponding to the media device.

8. The method of claim 2, further comprising: generating, for display in the virtual space, a first virtual representation associated with the first device; and generating, for display in the virtual space, one or more virtual representations respectively associated with the one or more other devices.

9. The method of claim 8, wherein the one or more virtual representations are one or more virtual avatars respectively associated with the one or more other devices, the method further comprising generating for display the one or more virtual avatars in the virtual space.

10. The method of claim 9, further comprising: exchanging protocol data between the first virtual representation and a virtual avatar of the one or more virtual avatars.

11. The method of claim 10, further comprising, based at least in part on the exchanging the protocol data, initiating communication between the first device and a device of the one or more other devices associated with the virtual avatar.

12. A system comprising: communication circuitry configured to transmit and receive data for a virtual space; and control circuitry configured to: generate, for display in the virtual space, a virtual representation of a media device, wherein the media device is externally connected to a first device, and wherein the first device is connected to the virtual space; receive, via the virtual representation displayed in the virtual space, a selection corresponding to the media device; and establish, based on connectivity information between the first device and the virtual space, a virtual connection for providing media content from the media device to one or more other devices connected to the virtual space.

13. The system of claim 12, wherein the control circuitry, when generating the virtual connection, is configured to generate a virtual bridge for joining respective communication paths between the first device and the one or more other devices via the virtual space.

14. The system of claim 12, wherein the control circuitry is further configured to: generate a respective virtual connection between the media device and each device of the one or more other devices, wherein the control circuitry is configured to transmit the media content to the each device via the respective virtual connection.

15. The system of claim 12, wherein the first device is externally connected to the media device via a local network.

16. The system of claim 12, wherein the first device is an extended reality (XR) wearable device.

17. The system of claim 12, wherein the control circuitry is further configured to: generate, for display in the virtual space, a user interface (UI) comprising one or more options corresponding to the media device.

18. The system of claim 12, wherein the control circuitry is further configured to: generate, for display in the virtual space, a first virtual representation associated with the first device; and generate, for display in the virtual space, one or more virtual representations respectively associated with the one or more other devices.

19. The system of claim 18, wherein the one or more virtual representations are one or more virtual avatars respectively associated with the one or more other devices, and wherein the control circuitry is further configured to generate for display the one or more virtual avatars in the virtual space.

20. The system of claim 19, wherein the control circuitry is further configured to: exchange protocol data between the first virtual representation and a virtual avatar of the one or more virtual avatars.

21. The system of claim 20, wherein the control circuitry is further configured to, based at least in part on exchanging the protocol data, initiating communication between the first device and a device of the one or more other devices associated with the virtual avatar.