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(54) **SYSTEMS AND METHODS FOR IMPROVING VOICE CALL QUALITY AND DEVICE LATENCY**

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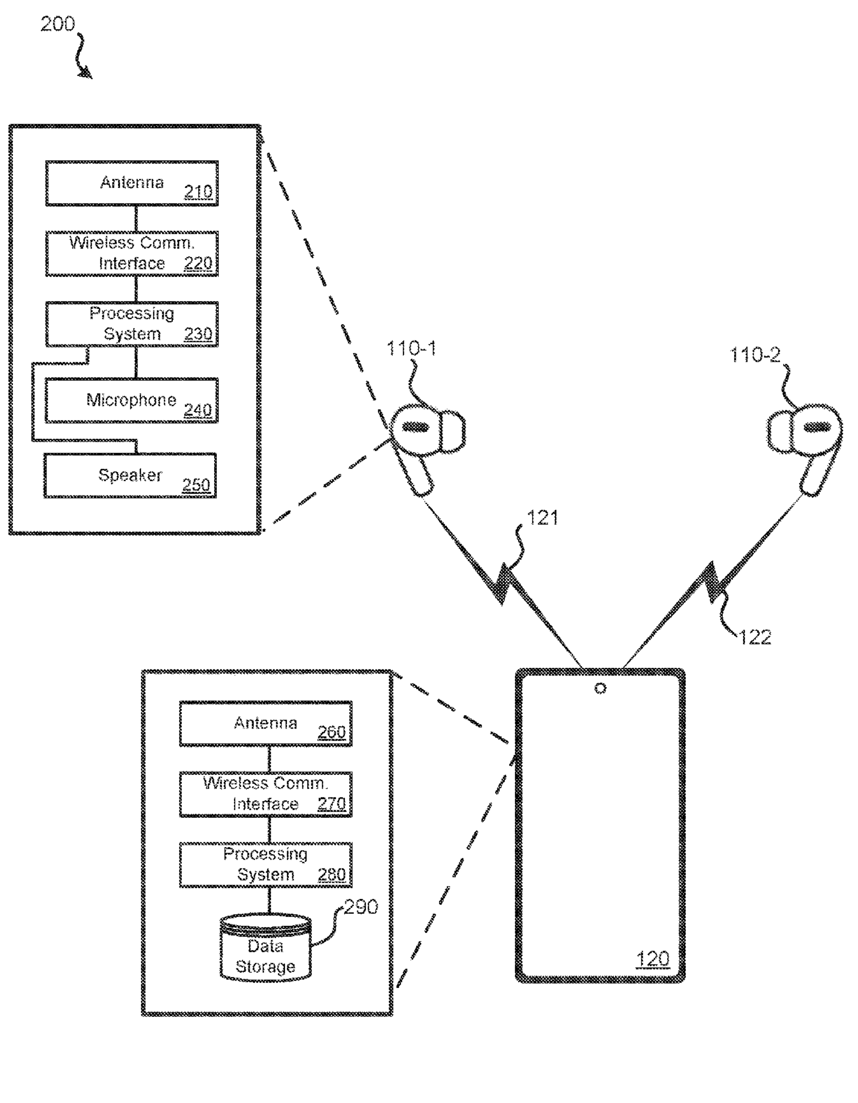
(57) **ABSTRACT**

Features described herein generally relate to systems and methods for improving voice call quality and device latency. A communication technique is disclosed in which a primary earbud of a set of earbuds acknowledges successful reception of the voice packet from a source device and transmits a data packet to a secondary earbud of set of earbuds when the secondary earbud is unable to successfully intercept and/or acquire the voice packet. Even if the secondary earbud does not intercept and/or otherwise acquire voice packet in a transmission from the source device to the primary earbud, the secondary earbud can receive the voice packet thereby improving voice call quality even in poor link conditions.



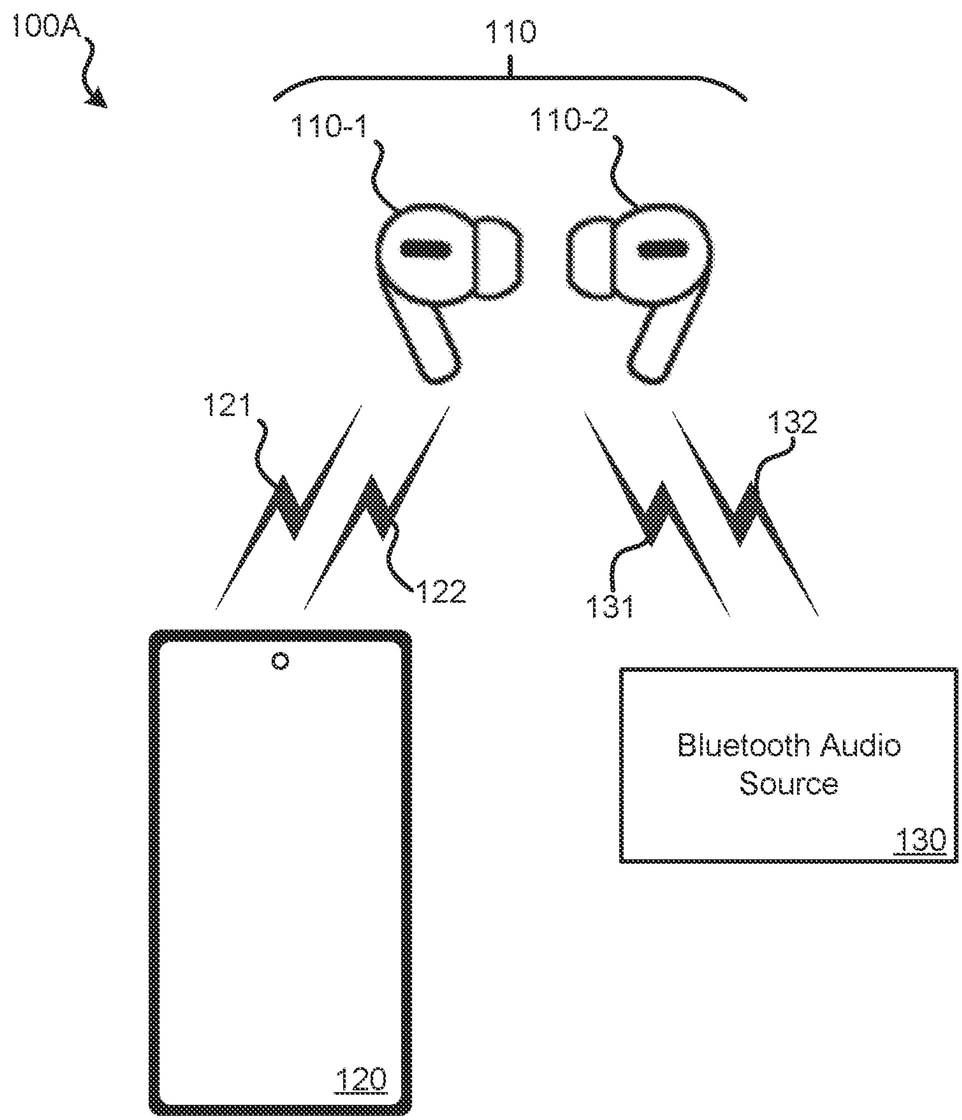

100A
110
110-1
110-2
121
122
131
132
Bluetooth Audio Source
130
120

FIG. 1A

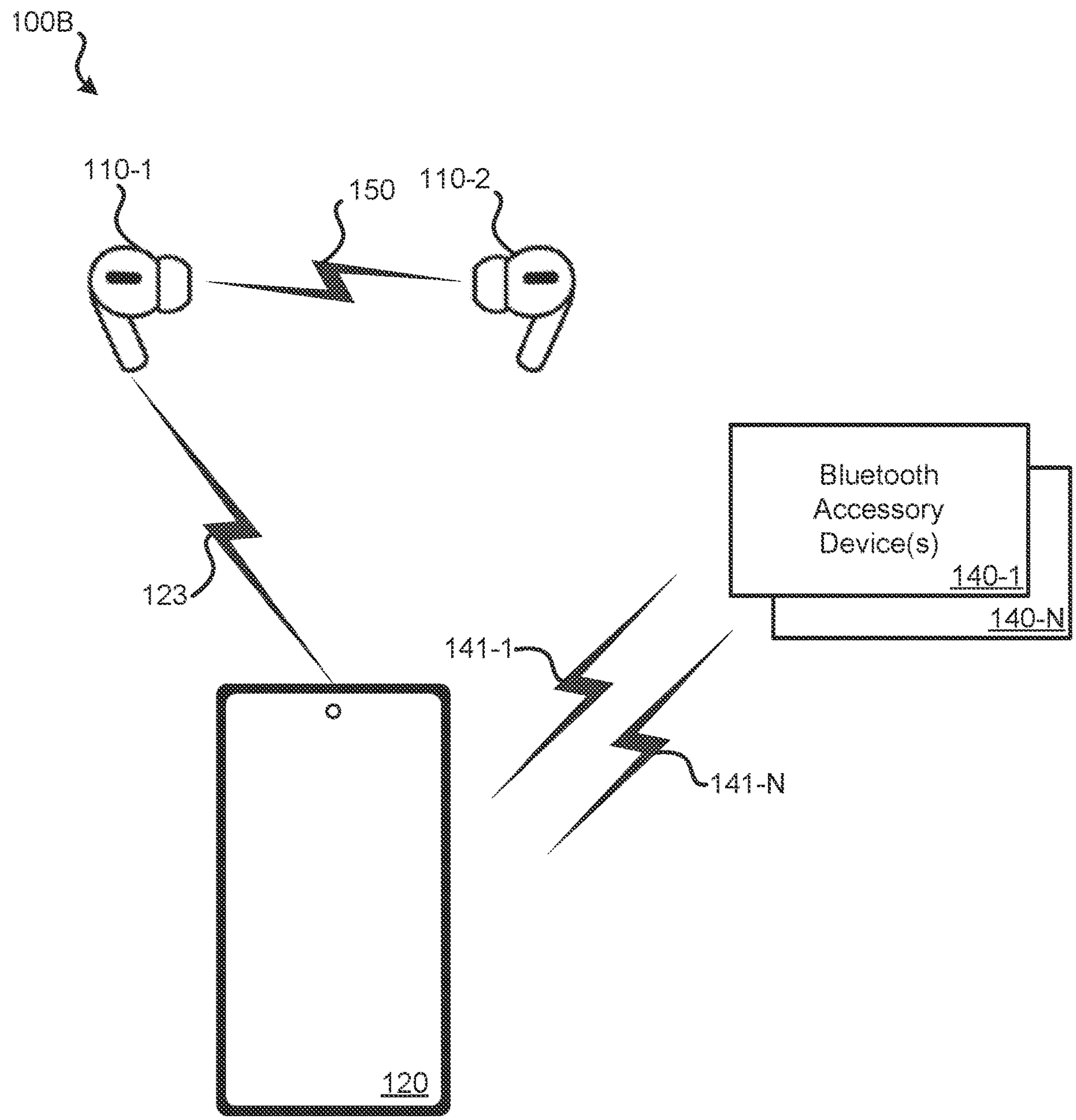

100B
110-1
150
110-2
123
Bluetooth
Accessory
Device(s)
140-1
140-N
141-1
141-N
120

FIG. 1B

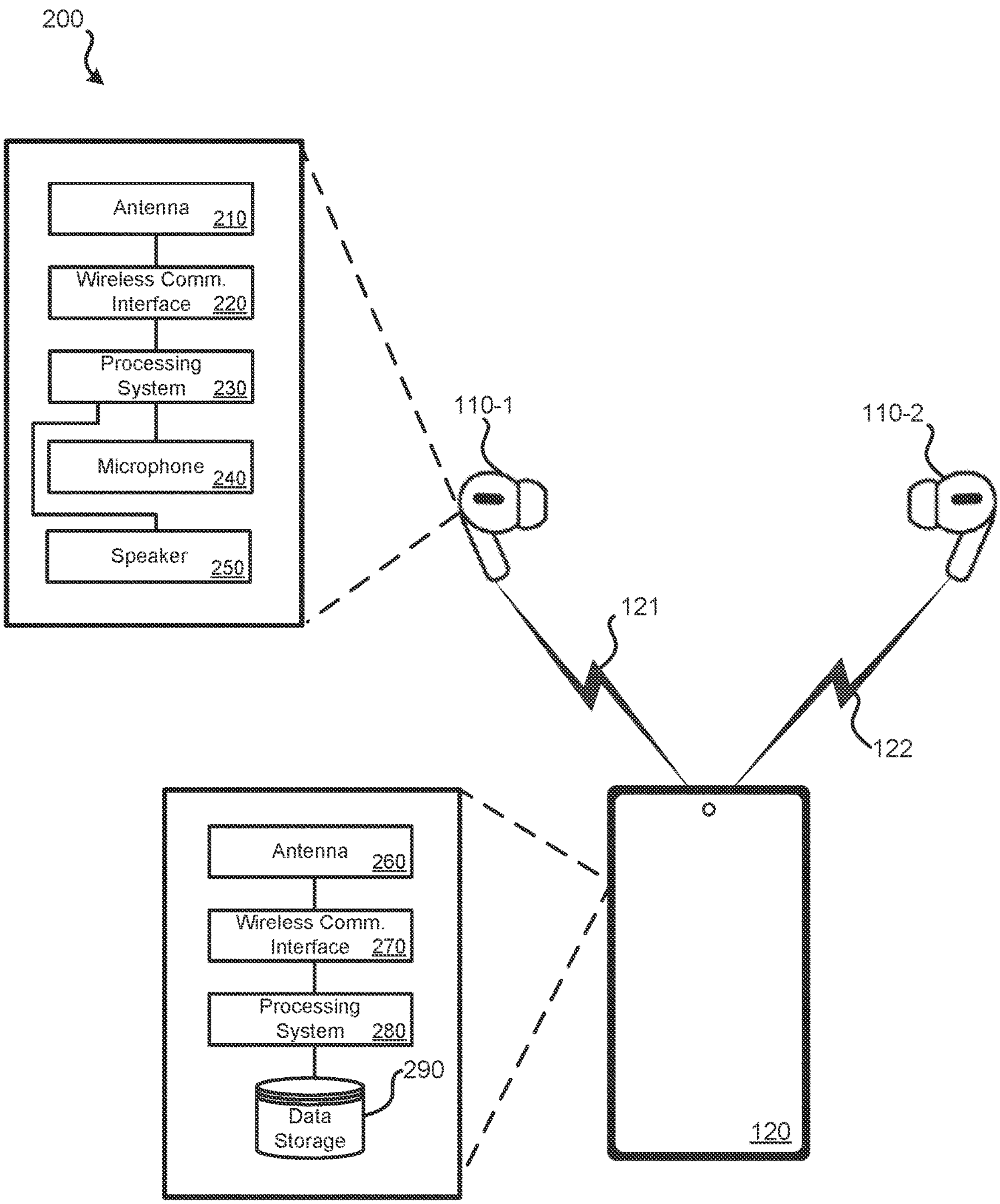

200
Antenna 210
Wireless Comm. Interface 220
Processing System 230
Microphone 240
Speaker 250
110-1
110-2
121
122
Antenna 260
Wireless Comm. Interface 270
Processing System 280
290
Data Storage
120

FIG. 2

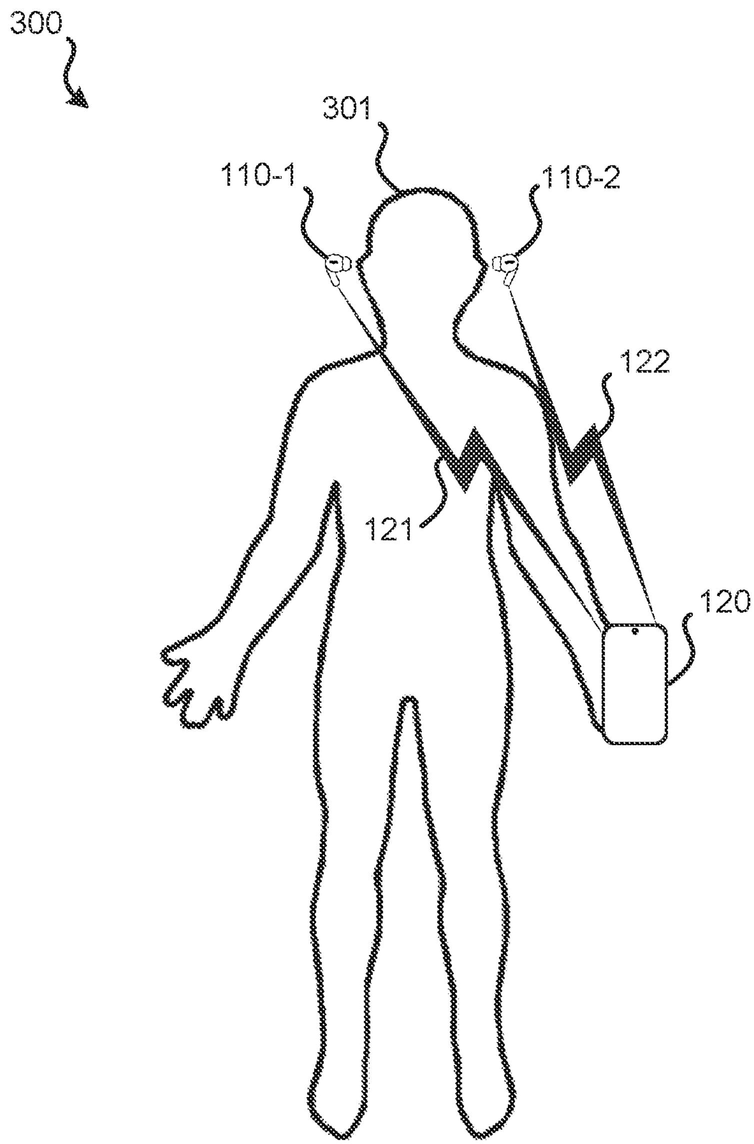


FIG. 3

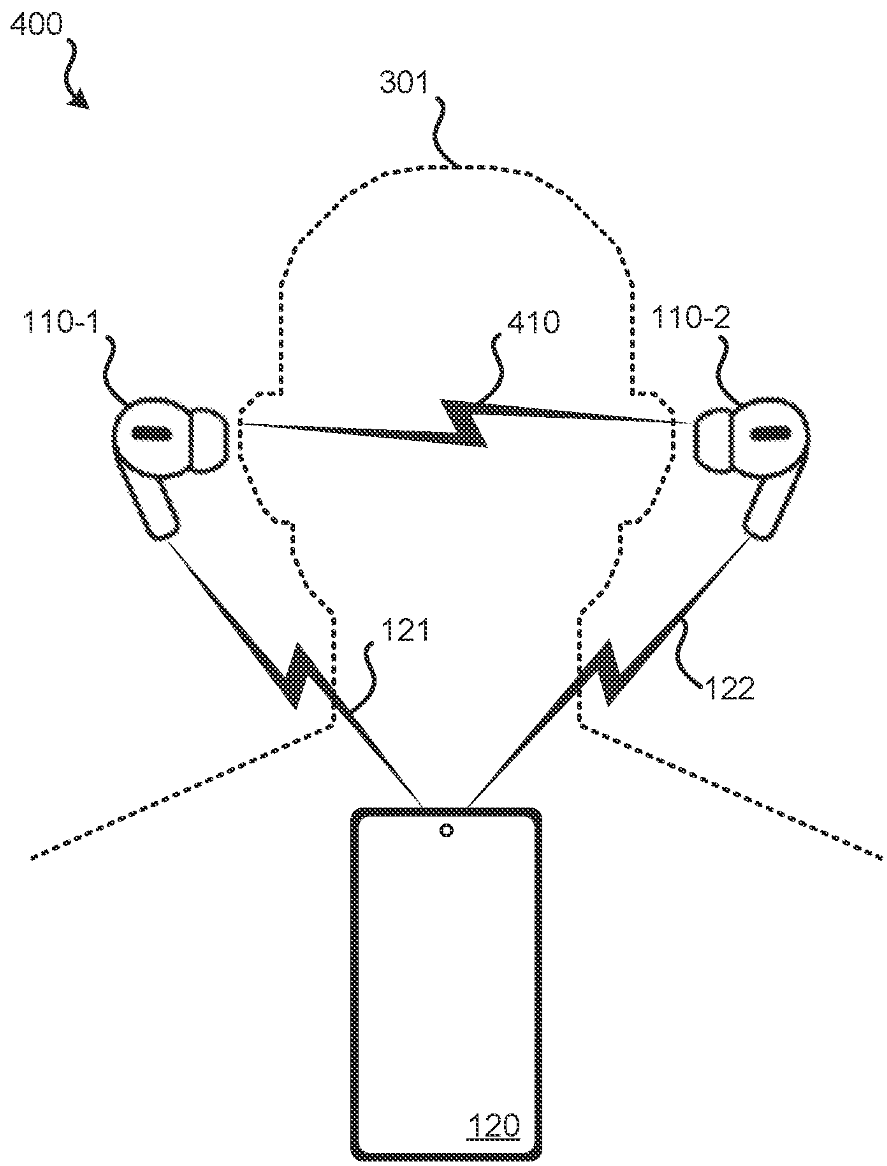


FIG. 4

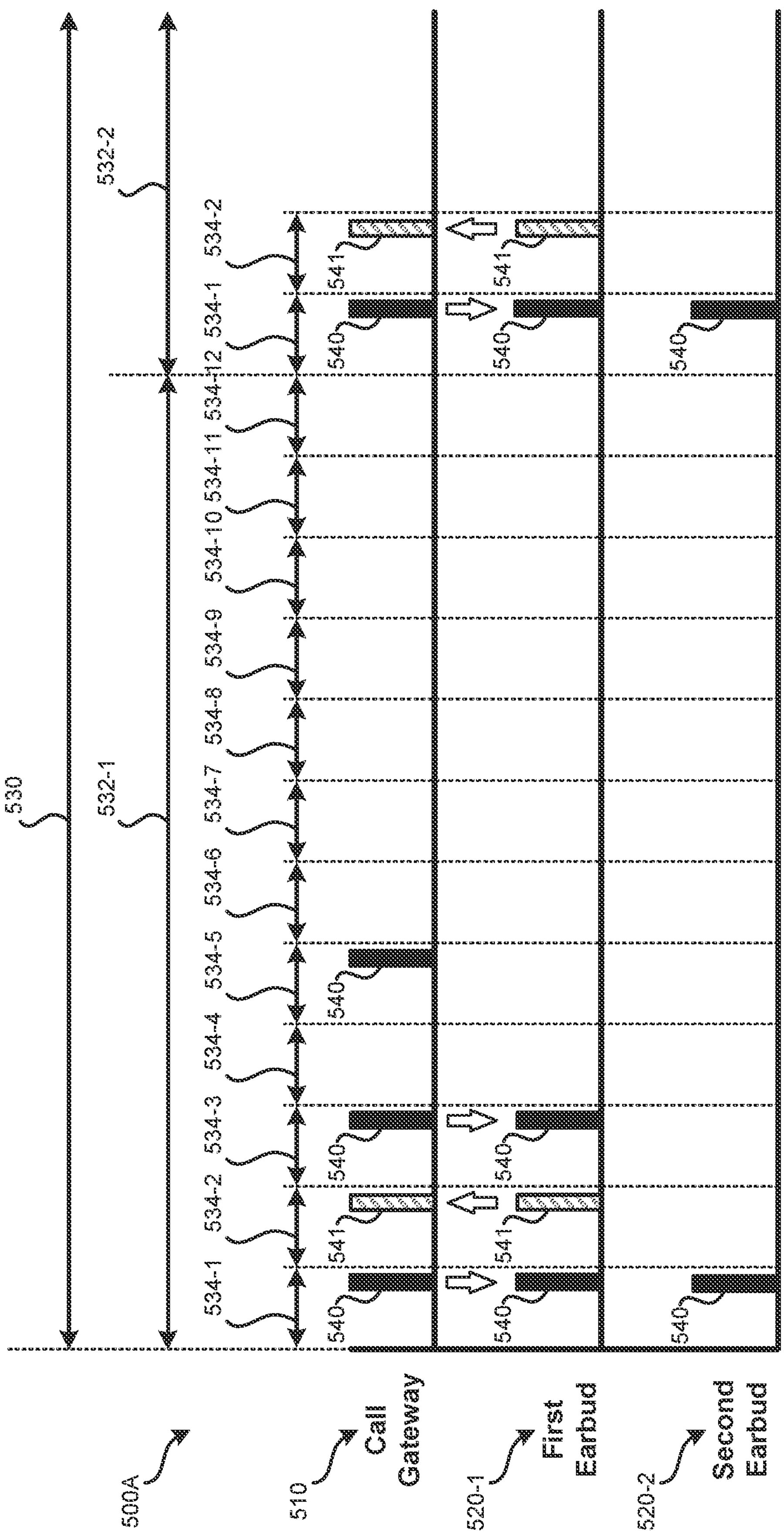

500A
510
Call Gateway
520-1
First Earbud
520-2
Second Earbud
530
532-1
532-2
534-1
534-2
534-3
534-4
534-5
534-6
534-7
534-8
534-9
534-10
534-11
534-12
534-1
534-2
540
541

FIG. 5A

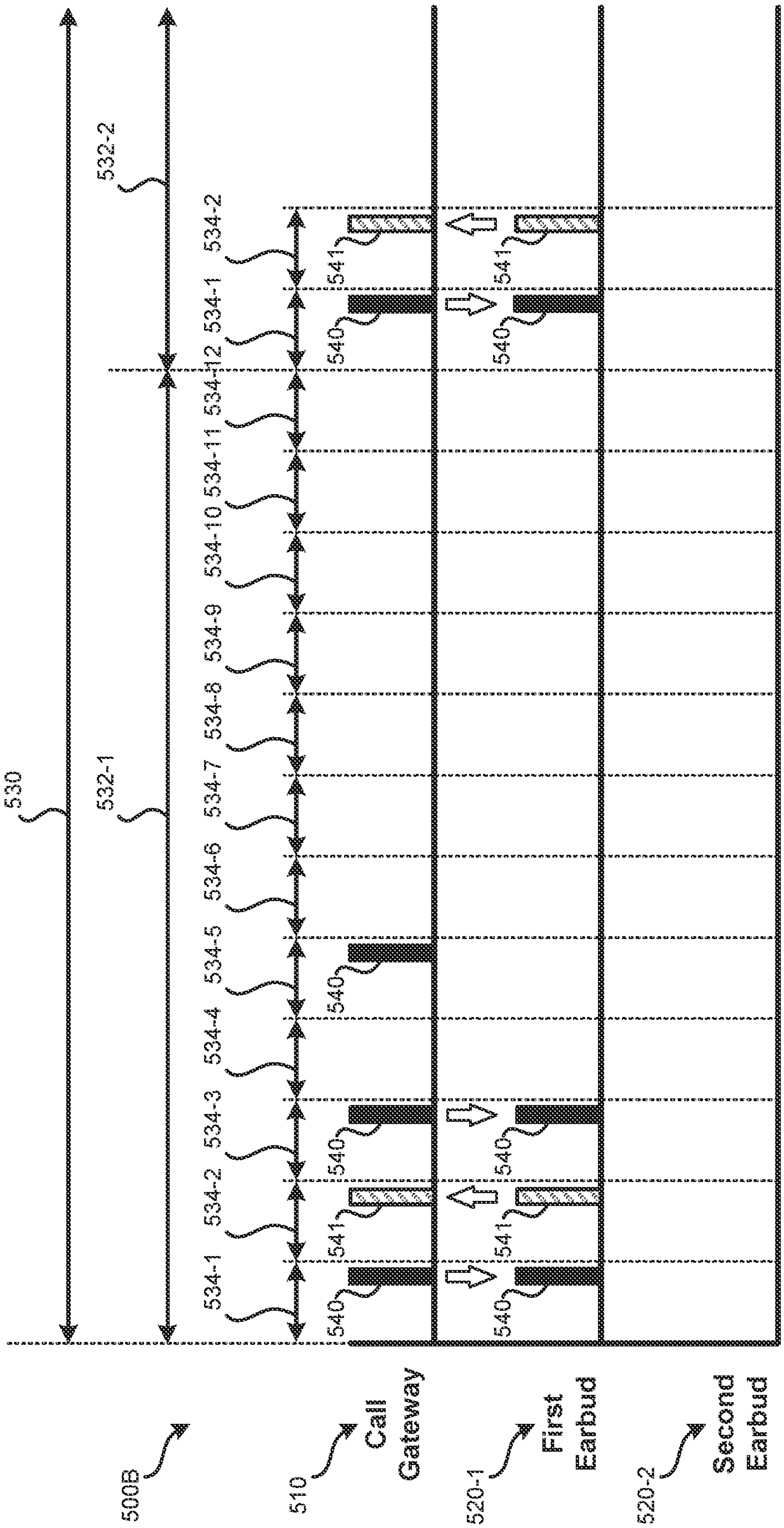

500B
510
Call Gateway
520-1
First Earbud
520-2
Second Earbud
530
532-1
532-2
534-1
534-2
534-3
534-4
534-5
534-6
534-7
534-8
534-9
534-10
534-11
534-12
534-1
534-2
540
541

FIG. 5B

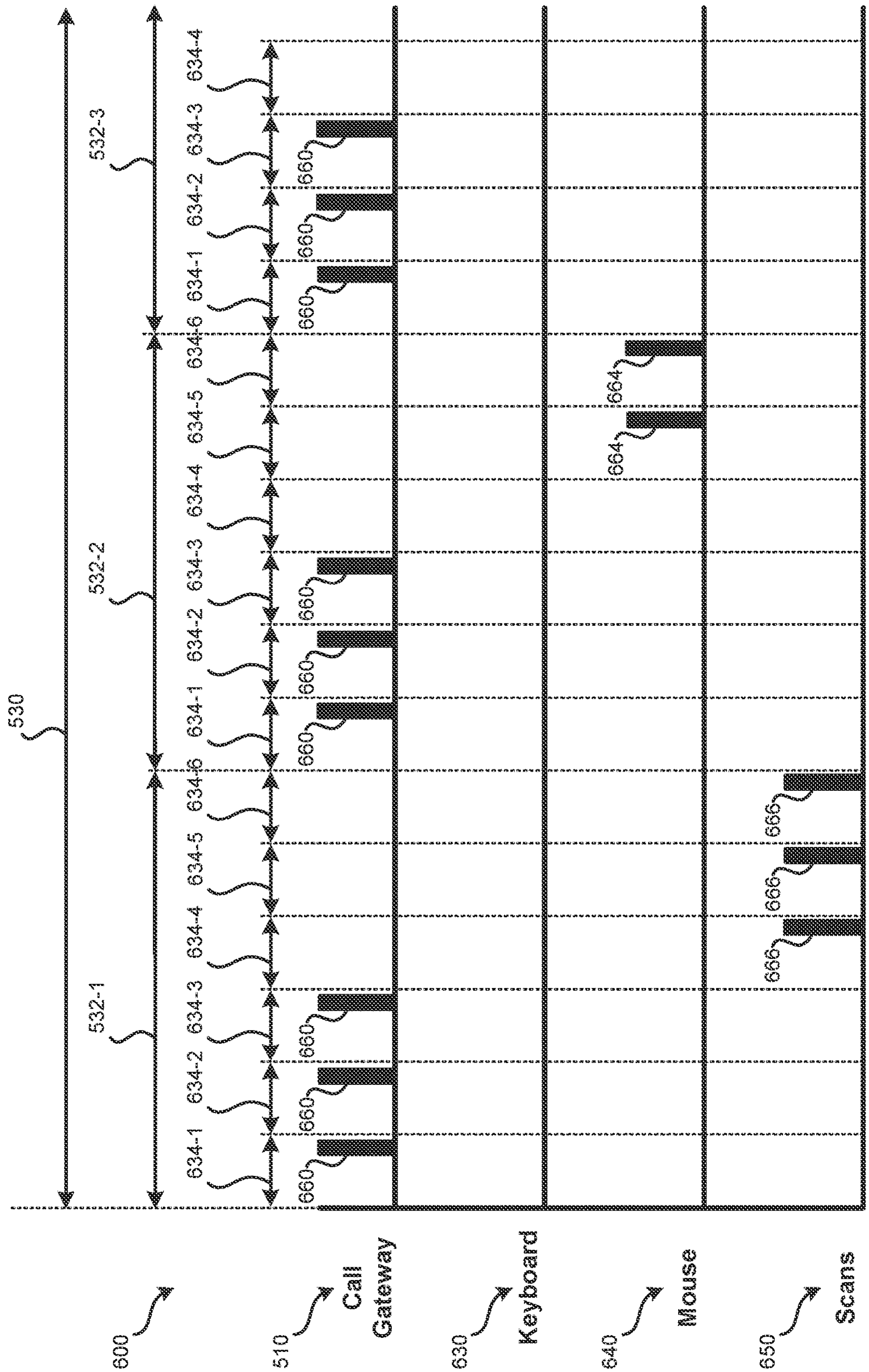

600
510
Call Gateway
630
Keyboard
640
Mouse
650
Scans
530
532-1
532-2
532-3
634-1
634-2
634-3
634-4
634-5
634-6
660
664
666

FIG. 6

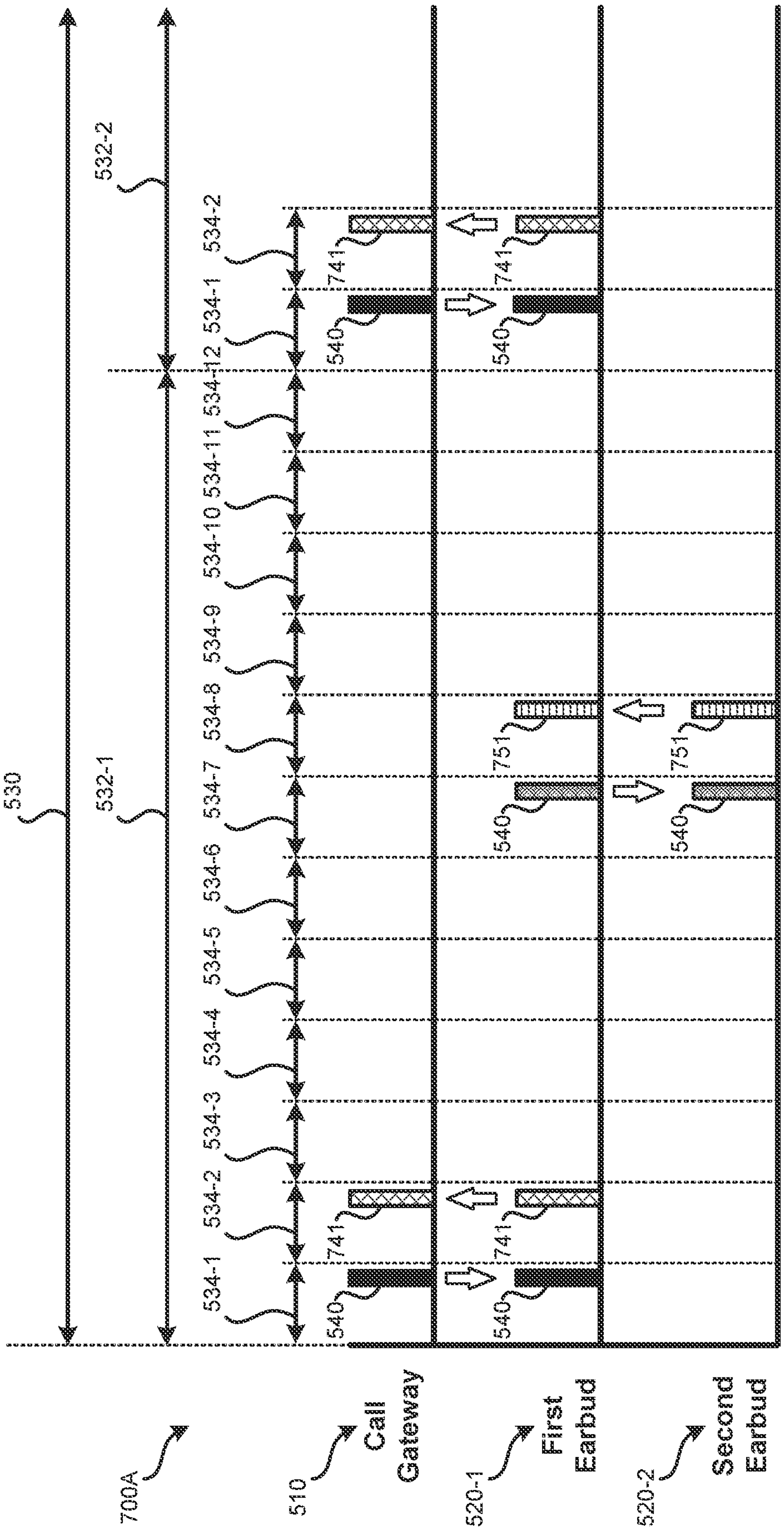

700A
510
Call Gateway
520-1
First Earbud
520-2
Second Earbud
530
532-1
532-2
534-1
534-2
534-3
534-4
534-5
534-6
534-7
534-8
534-9
534-10
534-11
534-12
540
741
751

FIG. 7A

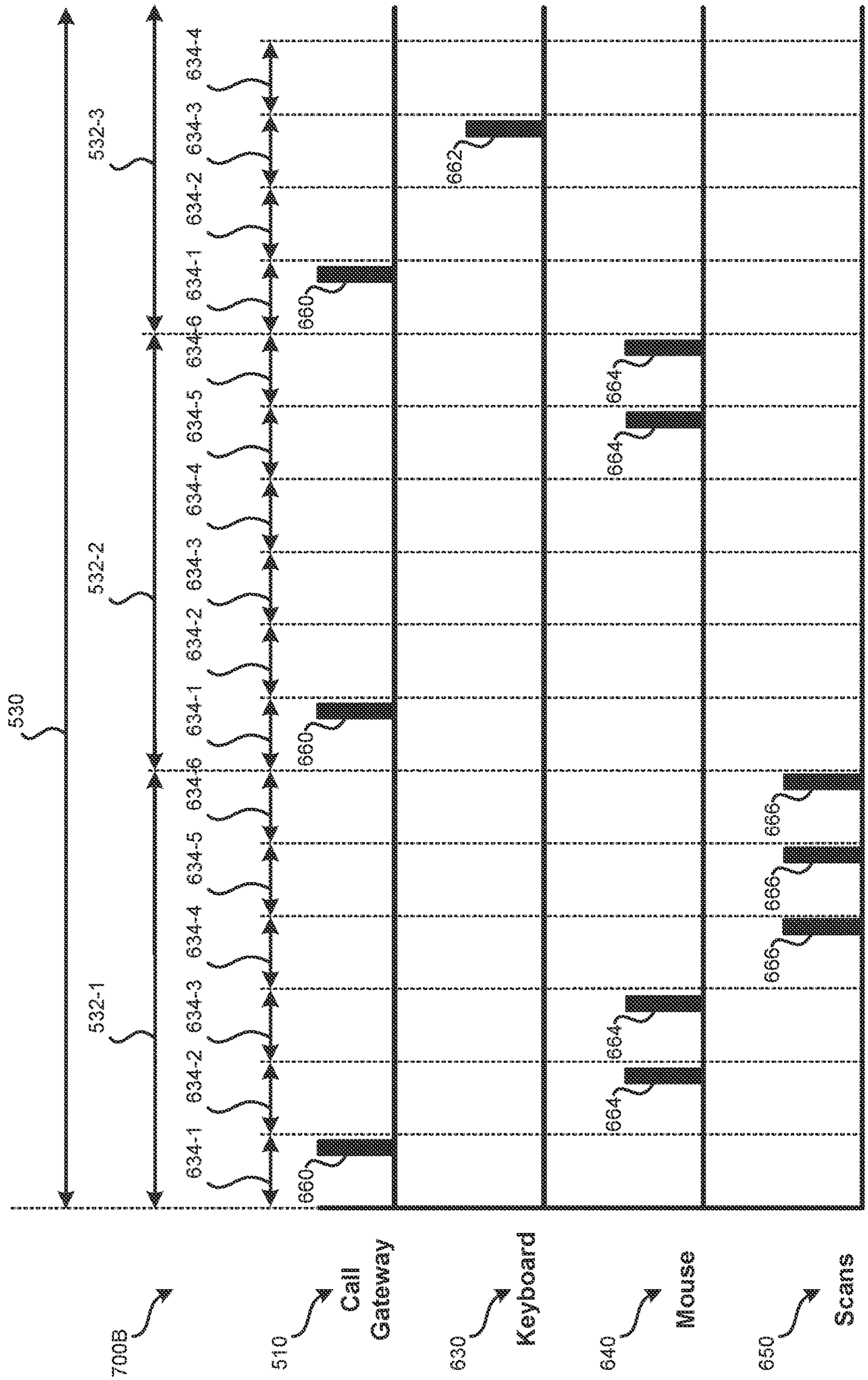

700B
510
Call Gateway
630
Keyboard
640
Mouse
650
Scans
530
532-1
532-2
532-3
634-1
634-2
634-3
634-4
634-5
634-6
660
662
664
666

FIG. 7B

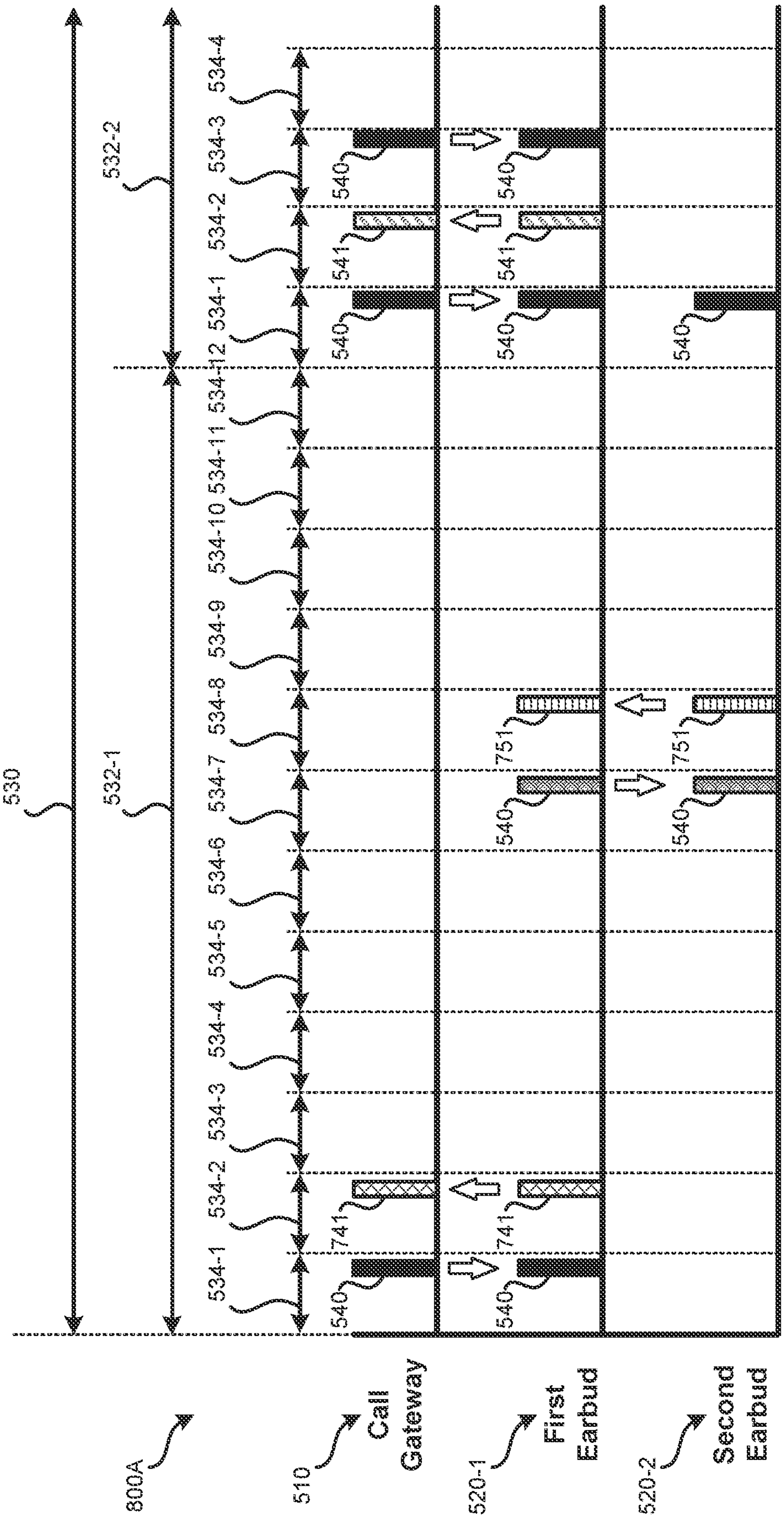

800A
510
Call Gateway
520-1
First Earbud
520-2
Second Earbud
530
532-1
532-2
534-1
534-2
534-3
534-4
534-5
534-6
534-7
534-8
534-9
534-10
534-11
534-12
534-1
534-2
534-3
534-4
540
741
751
541

FIG. 8A

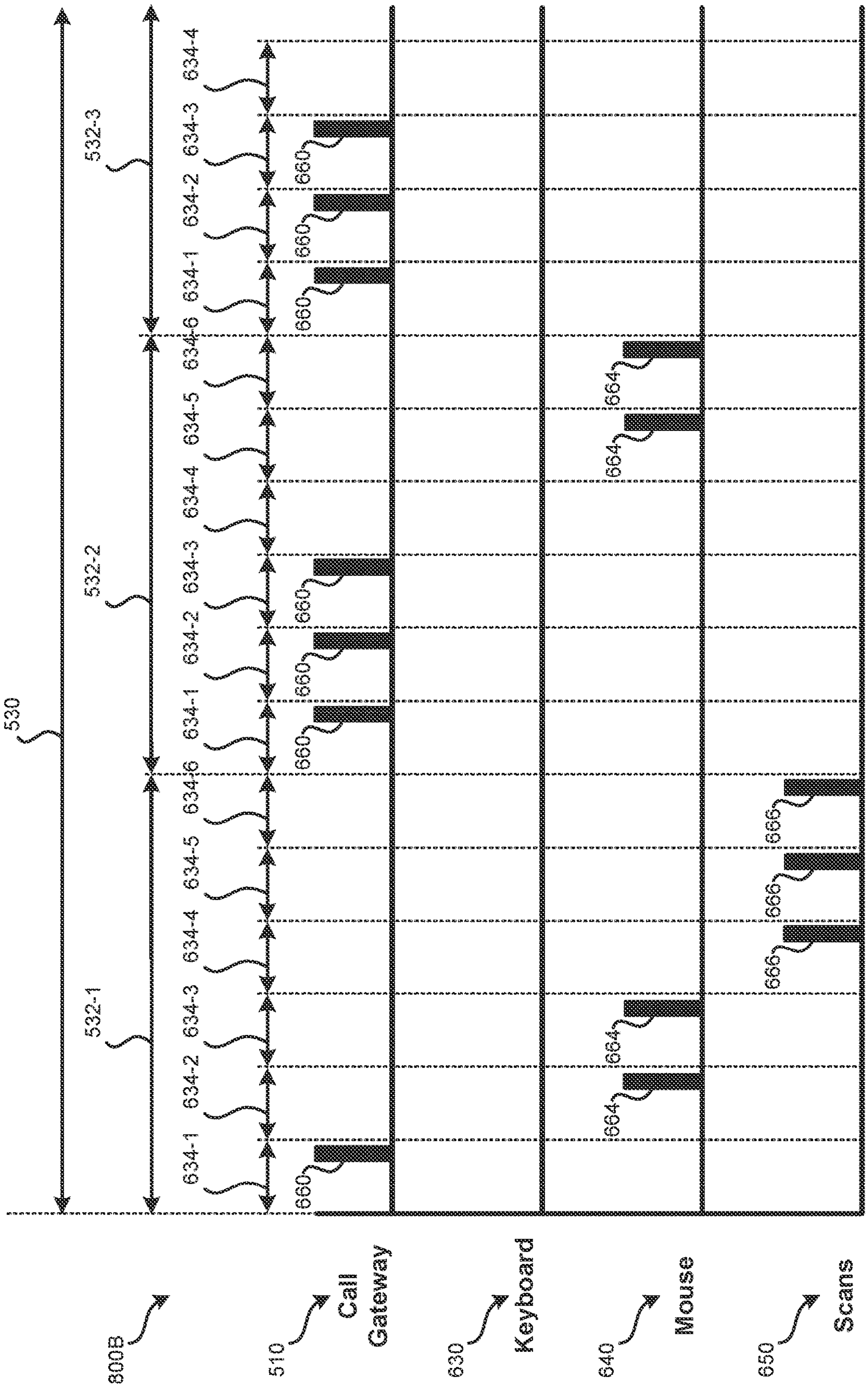

800B
510
Call Gateway
630
Keyboard
640
Mouse
650
Scans
530
532-1
532-2
532-3
634-1
634-2
634-3
634-4
634-5
634-6
660
664
666

FIG. 8B

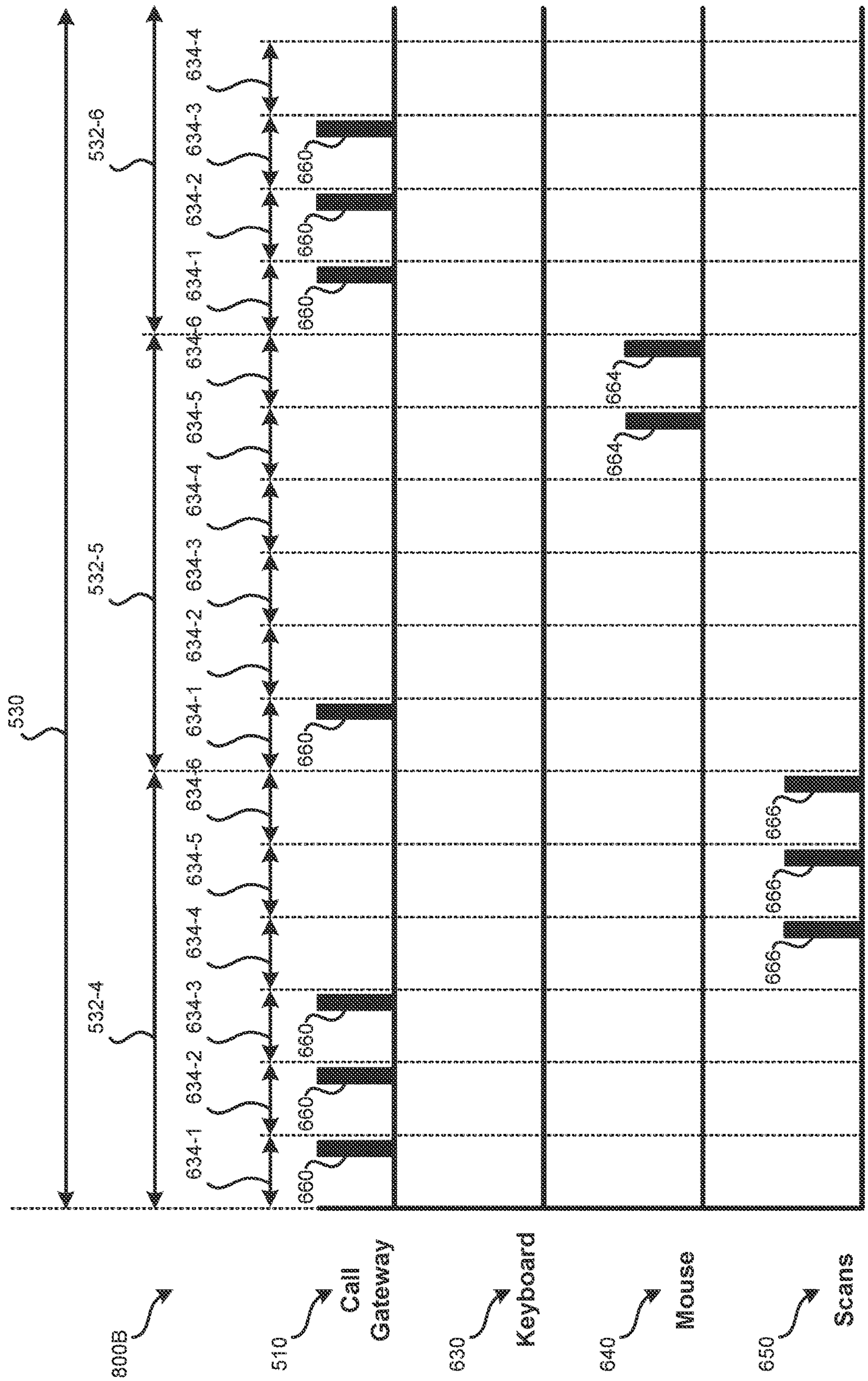

800B
510
Call Gateway
630
Keyboard
640
Mouse
650
Scans
530
532-4
532-5
532-6
634-1
634-2
634-3
634-4
634-5
634-6
660
664
666

FIG. 8C

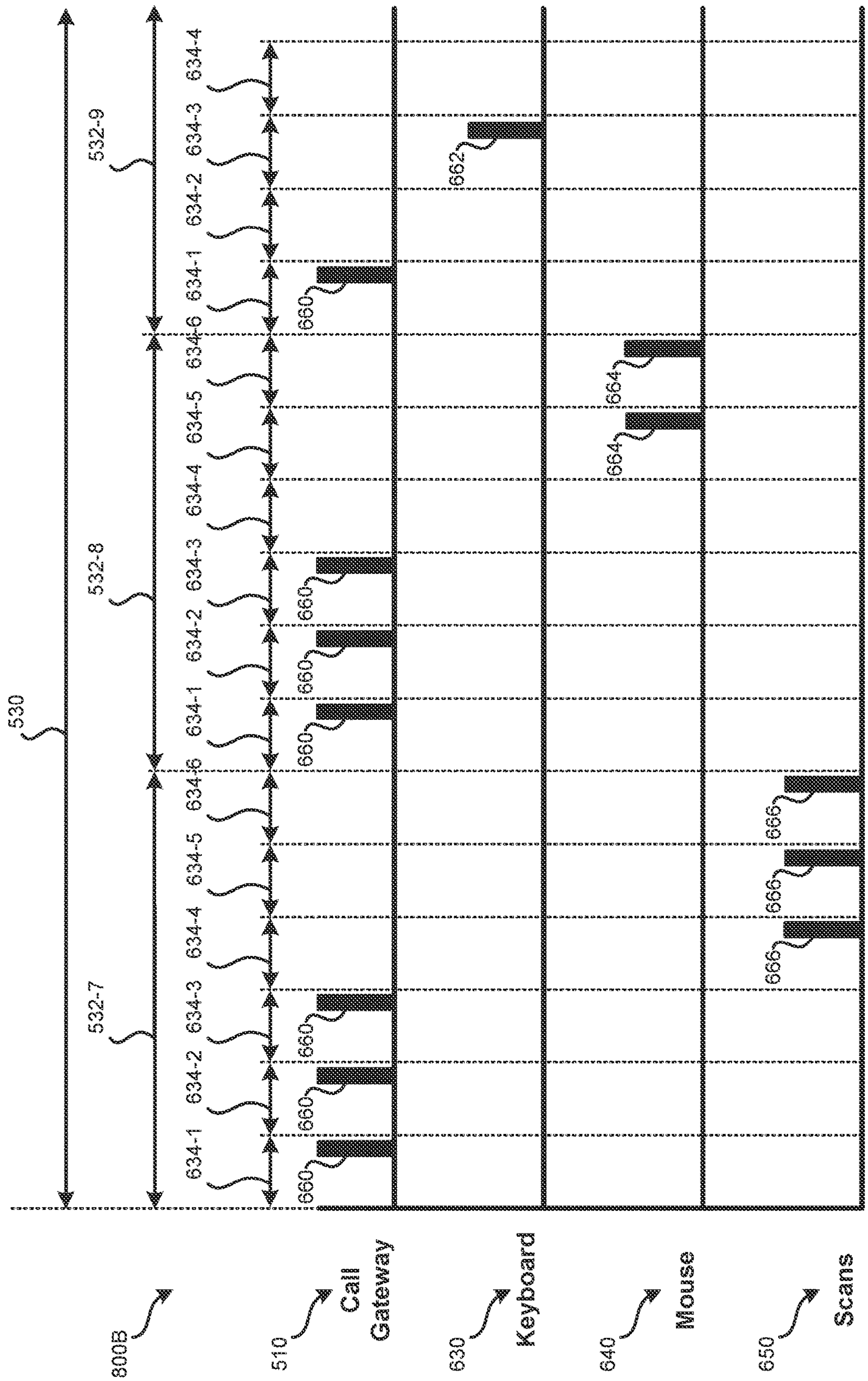

800B
510
Call Gateway
630
Keyboard
640
Mouse
650
Scans
530
532-7
532-8
532-9
634-1
634-2
634-3
634-4
634-5
634-6
634-1
634-2
634-3
634-4
634-5
634-6
634-1
634-2
634-3
634-4
660
660
660
660
660
660
660
662
664
664
666
666
666

FIG. 8D

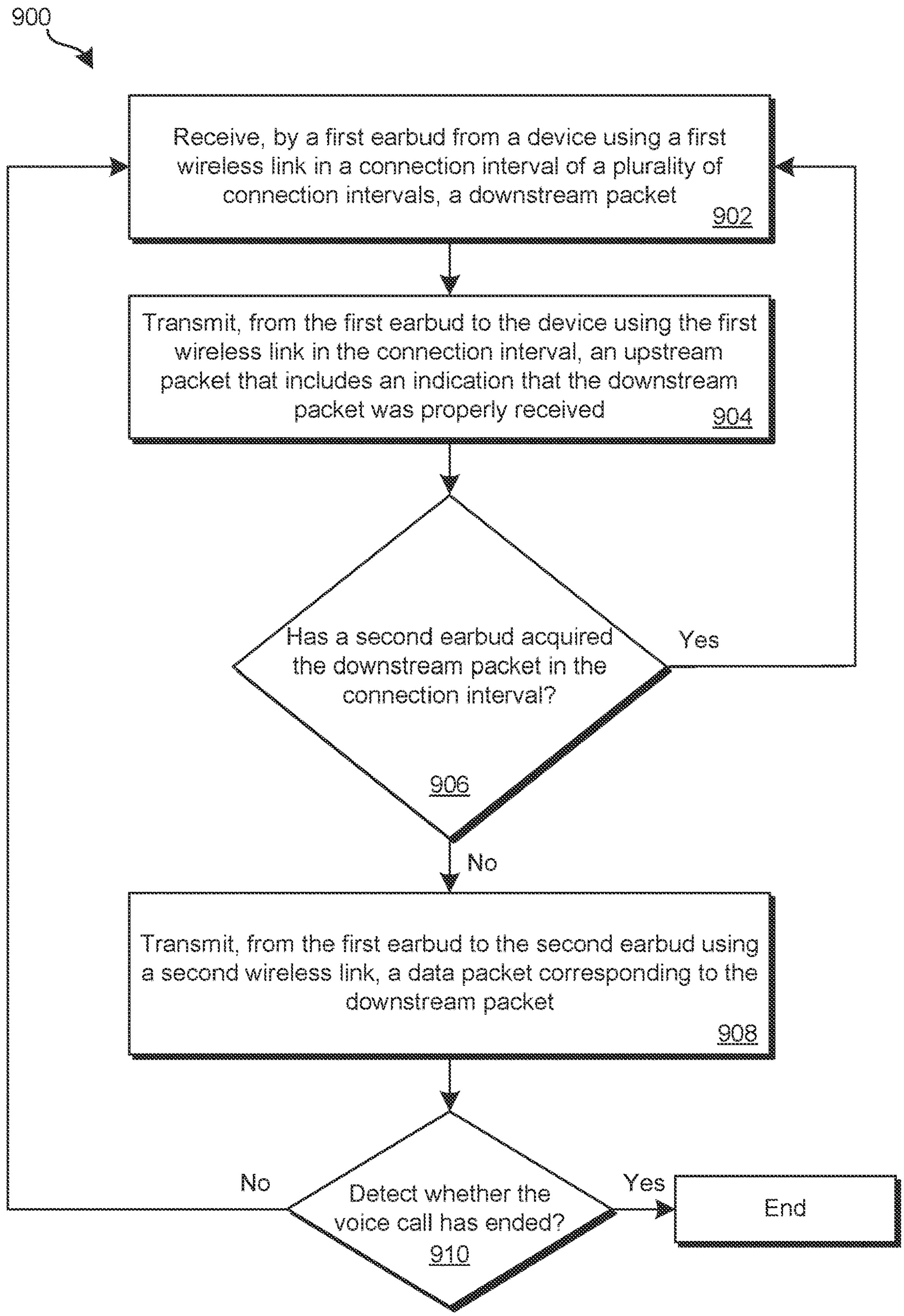

900
Receive, by a first earbud from a device using a first wireless link in a connection interval of a plurality of connection intervals, a downstream packet
902
Transmit, from the first earbud to the device using the first wireless link in the connection interval, an upstream packet that includes an indication that the downstream packet was properly received
904
Has a second earbud acquired the downstream packet in the connection interval?
906
Yes
No
Transmit, from the first earbud to the second earbud using a second wireless link, a data packet corresponding to the downstream packet
908
No
Detect whether the voice call has ended?
910
Yes
End

FIG. 9

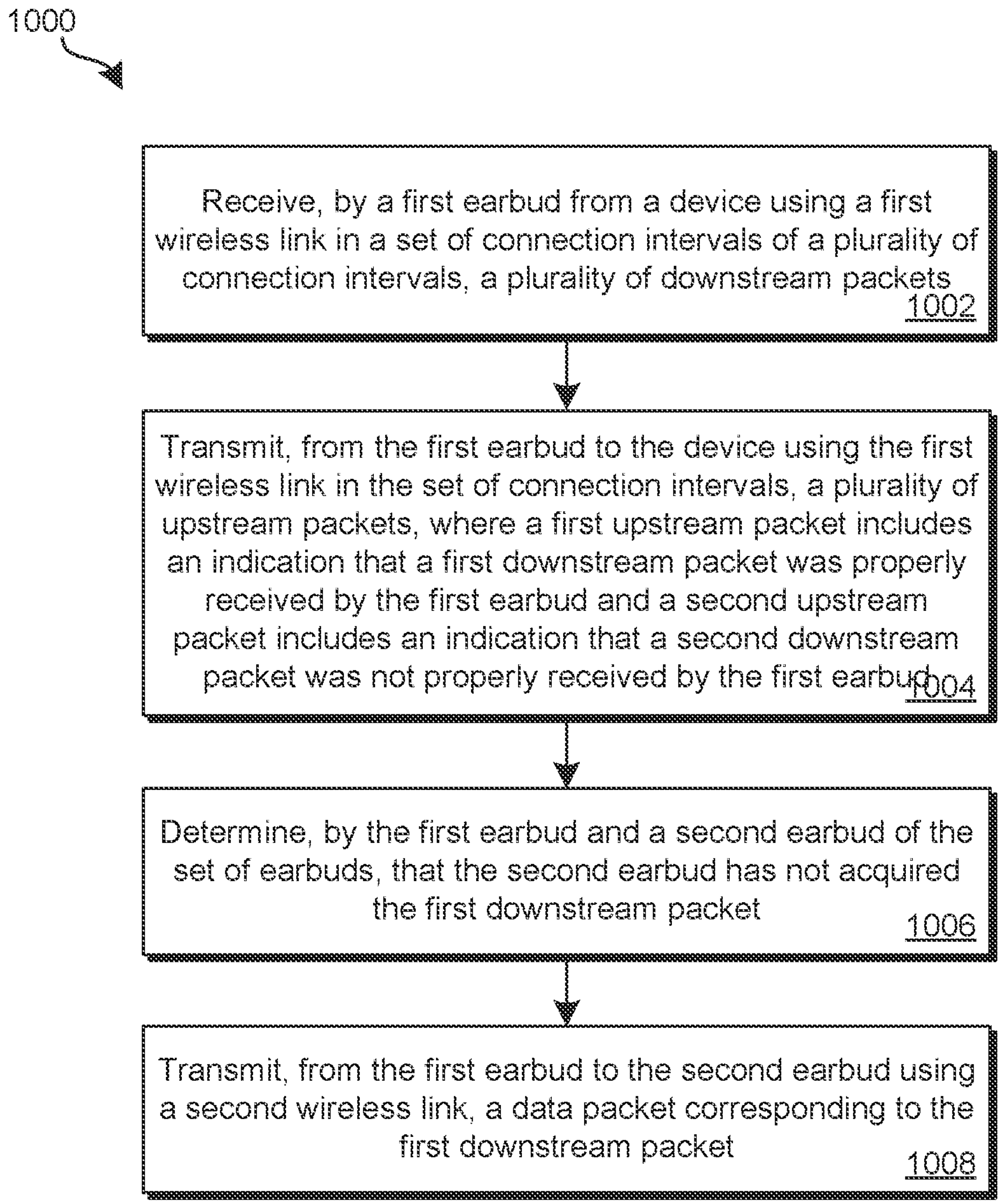

1000
Receive, by a first earbud from a device using a first wireless link in a set of connection intervals of a plurality of connection intervals, a plurality of downstream packets
1002
Transmit, from the first earbud to the device using the first wireless link in the set of connection intervals, a plurality of upstream packets, where a first upstream packet includes an indication that a first downstream packet was properly received by the first earbud and a second upstream packet includes an indication that a second downstream packet was not properly received by the first earbud
1004
Determine, by the first earbud and a second earbud of the set of earbuds, that the second earbud has not acquired the first downstream packet
1006
Transmit, from the first earbud to the second earbud using a second wireless link, a data packet corresponding to the first downstream packet
1008

FIG. 10

SYSTEMS AND METHODS FOR IMPROVING VOICE CALL QUALITY AND DEVICE LATENCY

CROSS-REFERENCES TO RELATED APPLICATIONS

[0001] This application claims priority to, and the benefit of U.S. Provisional Patent Application No. 63/400,810, filed Aug. 25, 2022, the entire disclosure of which is incorporated by reference in its entirety for all purposes.

BACKGROUND

[0002] Short-range wireless technologies such as Bluetooth, have enabled extended and remote functionality between devices. As such, users have come to rely on these technologies and expect seamless, glitch-free, and otherwise high-quality experiences while using their Bluetooth-enabled devices. These technologies continue to grow in popularity and, as more devices incorporate these technologies, bandwidth allocation between devices is challenging.

SUMMARY

[0003] Embodiments described herein pertain to systems and methods for improving voice call quality and device latency.

[0004] In various embodiments, a method for controlling a set of earbuds includes: receiving, by a first earbud of the set of earbuds from a device using a first wireless link in a set of connection intervals of a plurality of connection intervals, a plurality of downstream packets; and transmitting, from the first earbud to the device using the first wireless link in the set of connection intervals, a plurality of upstream packets, wherein a first upstream packet of the plurality of upstream packets comprises an indication that a first downstream packet of the plurality of downstream packets was properly received by the first earbud, and wherein a second upstream packet of the plurality of upstream packets comprises an indication that a second downstream packet of the plurality of downstream packets was not properly received by the first earbud.

[0005] In some embodiments, the first wireless link is a Bluetooth Basic Rate/Enhanced Data Rate (Bluetooth BR/EDR) link.

[0006] In some embodiments, the method further includes: determining, by the first earbud and a second earbud of the set of earbuds, that the second earbud has not acquired the first downstream packet; and in response to determining that the second earbud has not acquired the first downstream packet, transmitting, from the first earbud to the second earbud using a second wireless link, a data packet corresponding to the first downstream packet.

[0007] In some embodiments, the second wireless link is a Bluetooth Low Energy link.

[0008] In some embodiments, each upstream packet of the plurality of upstream packets comprises voice information of a user participating in a voice call using the set of earbuds.

[0009] In some embodiments, each downstream packet of the plurality of downstream packets is received in a first slot of a plurality of slots of each connection interval of the set of connection intervals.

[0010] In some embodiments, each upstream packet of the plurality of upstream packets is transmitted in a second slot of the plurality of slots of each connection interval of the set of connection intervals, the second slot of a respective connection interval of the set of connection intervals adjacent to the first slot of the respective connection interval.

[0011] Some embodiments include a system that includes a processing system and at least one computer-readable medium storing instructions which, when executed by the processing system, cause the system to perform part or all of the operations and/or methods disclosed herein.

[0012] Some embodiments include a non-transitory computer-readable medium storing instructions which, when executed by a processing system of an earbud, cause the earbud to perform part or all of the operations and/or methods disclosed herein.

[0013] The techniques described above and below may be implemented in a number of ways and in a number of contexts. Several example implementations and contexts are provided with reference to the following figures, as described below in more detail. However, the following implementations and contexts are but a few of many.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] A further understanding of the nature and advantages of various embodiments may be realized by reference to the following figures. In the appended figures, similar components or features may have the same reference label. Further, various components of the same type may be distinguished by following the reference label by a dash and a second label that distinguishes among the similar components. If only the first reference label is used in the specification, the description is applicable to any one of the similar components having the same first reference label irrespective of the second reference label.

[0015] FIG. **1**A illustrates an embodiment of an audio system.

[0016] FIG. **1**B illustrates another embodiment of an audio system.

[0017] FIG. **2** illustrates an embodiment of a block diagram of an audio system that includes a pair of true wireless earbuds communicating with an audio source.

[0018] FIG. **3** illustrates an embodiment of cross-body attenuation resulting in communication between an audio source and a first earbud experiencing more attenuation than communication between the audio source and the second earbud.

[0019] FIG. **4** illustrates an embodiment of an audio system in which true wireless earbuds communicate with each other in addition to communicating with an audio source.

[0020] FIG. **5**A illustrates an embodiment of communication between a call gateway and true wireless earbuds during a voice call.

[0021] FIG. **5**B illustrates another embodiment of communication between a call gateway and true wireless earbuds during a voice call.

[0022] FIG. **6** illustrates an embodiment of communication between a call gateway and multiple accessory devices during a voice call.

[0023] FIG. **7**A illustrates another embodiment of communication between a call gateway and true wireless earbuds during a voice call.

[0024] FIG. **7**B illustrates another embodiment of communication between a call gateway and multiple accessory devices during a voice call.

[0025] FIG. **8**A illustrates another embodiment of communication between a call gateway and true wireless earbuds during a voice call.

[0026] FIGS. **8**B-**8**D illustrate another embodiment of communication between a call gateway and multiple accessory devices during a voice call.

[0027] FIG. **9** illustrates an embodiment of a method corresponding to the embodiments of FIGS. **7**A and **7**B.

[0028] FIG. **10** illustrates an embodiment of a method corresponding to the embodiments of FIGS. **8**A-**8**D.

DETAILED DESCRIPTION

[0029] Wireless audio playback devices such as true wireless earbuds offer a convenient way for users of electronic devices to participate in phone calls made by the electronic devices. For example, a user can initiate a phone call using an electronic device (e.g., a mobile phone, a personal computer, and the like) and use true wireless earbuds to participate in the call without physically holding the electronic device in their hands. In a typical scenario, once a call is initiated on the electronic device, a first audio signal corresponding to the call is transmitted from the electronic device to the earbuds where a speaker of the earbuds outputs the received audio to the user, and a second audio signal corresponding to the call is received at a microphone of the earbuds and transmitted to the electronic device. True wireless earbuds often communicate with the electronic device using a short-range wireless technology that utilizes a Bluetooth-family communication protocol, such as Bluetooth Classic or Bluetooth LE. Often a user will use Bluetooth-based wireless communications concurrently for true wireless earbuds and multiple accessory devices such as a keyboard and mouse used to control their electronic device. Such an arrangement allows for simultaneously participation in calls initiated by the electronic device and perform other tasks with the electronic device such as surfing the Internet using the keyboard and mouse.

[0030] To enable such functionality, the electronic device or call gateway connects to and transmits a voice packet to a first earbud (i.e., the primary earbud). While the call gateway does not connect to the second earbud, the second earbud intercepts and/or otherwise acquires the voice packet transmitted to the primary earbud using a packet capturing technique such as sniffing. In this way, the first and second earbuds can receive the same voice packet even though the call gateway may not even be aware of the second earbud. To ensure the voice packet is received by the primary earbud, communication is configured between the primary earbud and call gateway such that the call gateway will typically transmit the voice packet multiple times even when the voice packet is successfully received by the primary earbud on the first attempt, which provides the secondary earbud multiple opportunities to receive the voice packet. This process is repeated in intervals throughout the duration of the call.

[0031] However, the foregoing arrangement leads to the following challenges. When the link condition between the call gateway and the primary earbud is good and the secondary earbud is able to acquire the voice packet transmitted to the primary earbud, bandwidth utilization at the call gateway leads to poor user experience for accessory devices connected to the call gateway during the call. For example, in the case of a keyboard or mouse, a user may experience a slow keyboard or mouse response while participating in a call using the earbuds. On the other hand, when there is a poor link condition between the call gateway and the primary earbud, the primary earbud and/or secondary earbud may be unable to intercept and/or otherwise acquire the voice packet, which, in addition to bandwidth utilization at the call gateway leading to poor user experience for accessory devices connected to the call gateway during the call, often results poor audio quality during the call.

[0032] The techniques described herein overcome these challenges and/or others by providing a communication technique for improving audio quality during voice calls and accessory device latency. As described above, during a voice call, communication between the primary earbud and the call gateway is configured such that the call gateway will transmit the voice packet to the primary earbud multiple times even after the primary earbud has successfully received the voice packet. The techniques described herein provide a communication technique in which the primary earbud acknowledges successful reception of the voice packet from a source device and transmits a data packet to the secondary earbud when the secondary earbud is unable to successfully intercept and/or acquire the voice packet. In this way, even if the secondary earbud does not intercept and/or otherwise acquire voice packet in a transmission from the call gateway to the primary earbud, the secondary earbud can receive the voice packet thereby improving voice call quality even in poor link conditions. In an implementation, the primary earbud acknowledges reception of the voice packet as soon as the voice packet is successfully received by the primary earbud. In another implementation, the primary earbud periodically acknowledges reception of the voice packet if it is successfully received in an interval. In this way, by acknowledging successful reception of a voice packet by the primary earbud, bandwidth utilization at the source device can be reduced thereby enabling the source device to improve latency of accessory devices connected to the source device.

[0033] "True wireless earbuds," as used herein, refer to earbuds that both: 1) receive audio packets (e.g., voice packets) wirelessly from one or more audio sources; and 2) are not physically connected with each other, such as via a wire. Therefore, in a pair of true wireless earbuds, each earbud must have its own power supply and wireless communication interface to allow for communication. As described herein, embodiments of earbuds, unless otherwise noted, are directed to true wireless earbuds. Additionally, while the techniques described herein are described with respect to communication between a call gateway device and among earbuds, it should be understood that at least some techniques described herein can have additional applicability. For example, communication techniques described herein could be used in arrangements including one or more computing devices such as one or more smart display and wireless stereo speakers to improve performance.

[0034] FIGS. **1**A and **1**B illustrate embodiments of an audio system. As shown in FIG. **1**A, audio system **100**A can include earbuds **110** (which can include earbud **110-1** and earbud **110-2**), audio source **120**, and audio source **130**, and, as shown in FIG. **1**B, audio system **100**B can include earbuds **110**, audio source **120**, and accessory devices **140** (which can include multiple accessory devices **140-1**, . . . **140**-N). Although not shown. audio system **100**A can also include accessory devices such as accessory devices **140**.

Similarly, audio system **100**B can also include additional audio sources such as audio source **130**.

[0035] Audio source **120** can represent various forms of computerized devices capable of Bluetooth communications. As illustrated, one possible form of audio source **120** is a smartphone. For example, a smartphone can output stereo audio (e.g., music, gaming audio, audio for an audio or video conference) and mono audio (e.g., audio for a telephone call, mono audio for an audio or video conference). Many other forms of audio source **120** may be possible, such as: a tablet computer, a gaming device, a laptop computer, a desktop computer. a stereo system, and a television. More generally, any computerized device that outputs Bluetooth audio can serve as audio source **120**. In some embodiments, audio source **120**, when used for voice phone calls, can alternatively be used as and referred to as a call gateway. (In voice call terminology, earbuds **110** can be referred to as a "call terminal.")

[0036] In general, Bluetooth-family protocols are used as the short-range wireless technology standards for exchanging data between audio source **120** (and possibly audio source **130**) and earbuds **110** and between audio source **120** and accessory devices **140**. Within the Bluetooth-family, various versions of Bluetooth may be used, depending on the particular embodiment. Bluetooth Basic Rate/Enhanced Data Rate (Bluetooth BR/EDR), which is also referred to as Bluetooth "Classic," can be used in various embodiments as detailed herein. Some embodiments detailed herein rely on Bluetooth Low Energy (LE) or LE Audio as the specific Bluetooth-family protocol for communication. The same hardware may be used to implement any of these Bluetooth-family protocols.

[0037] Depending on the version of Bluetooth that is used, one or more Bluetooth profiles may be used to define a connection/communication protocol between a central (or first) device and peripheral (or second) device(s) and between peripheral devices. For example, the connection/communication protocol between the audio source **120** and earbuds **110** may be defined by the Advanced Audio Distribution Profile (A2DP) and/or the Hands-Free Profile (HFP). Similarly, the connection/communication protocol between the audio source **120** and the accessory devices **140** may be defined by the Human Interface Device (HID) Profile. The foregoing profiles are not intended to be limiting and the various embodiments described herein can use other Bluetooth profiles such as the Headset Profile (HSP) and the Mesh Profile (MESH).

[0038] Further, embodiments detailed herein may use one or more of these Bluetooth-family protocols as a starting point but may have additional features that go beyond the specification of the standard. These additional features require both an audio source and earbuds that are compatible with the additional features to be used in order for the additional features to be available. As an example, one manufacturer may produce earbuds and audio sources (e.g., smartphones, laptop computers, tablet computers) that support additional features that go beyond the minimum features of a Bluetooth-family protocol when used together. However, when one of such devices is used with another manufacturer's devices, such additional features beyond the Bluetooth-family may not be available unless the manufacturers have cooperated on implementing the additional features.

[0039] While the embodiments detailed herein are focused on improvements to Bluetooth-family protocols, it should be understood that the embodiments detailed herein can also be applied to other short-range wireless technologies that could be used to enable communication between devices. For example, the embodiments detailed herein are equally applicable to the following technologies: infrared data association (IrDA); radio frequency identification (RFID); wireless local access network (WLAN); near field communication (NFC); ZigBee: Z-wave; wireless fidelity (Wi-Fi) and wireless fidelity direct (Wi-Fi Direct); ultra-wideband (UWB); ANT and ANT+; third generation (3G), fourth generation (4G), fifth generation (5G), and sixth generation (6G), and the like.

[0040] As illustrated in FIG. **1**A, separate data streams may be used between an audio source and each earbud of earbuds **110**. In a Bluetooth LE or LE Audio scenario, a connected isochronous stream (CIS) or broadcast isochronous stream (BIS) may be present on link **121** from audio source **120** to earbud **110-1**. A separate CIS or BIS may be present as part of link **122** to earbud **110-2**. If audio is being transmitted from an earbud of earbuds **110** to audio source **120** (e.g., from a microphone of an earbud for a phone call), another CIS or BIS may be present from an earbud to audio source **120**. Alternatively, the same CIS or BIS can be used for transmitting microphone audio from an earbud to audio source **120**. Separate CISs or BISs may also exist as part of wireless communications **131** and wireless communications **132** between an additional audio source such as audio source **130** and earbuds **110**. Separately, between each audio source and each earbud, can be another channel, referred to as an asynchronous connection-oriented link (ACL) that allows for control data to be transmitted between the audio source and the particular earbud in both directions.

[0041] While one or more active communication channels are present between audio source **120** and earbuds **110**, one or more separate active communication channels can be present between earbuds **110** and audio source **130**. Again here many other audio sources may be possible, such as: a tablet computer, a gaming device, a laptop computer, a desktop computer, a computerized music device, a stereo system, a television, or any computerized device that can output Bluetooth audio can serve as audio source **130**.

[0042] Various use cases exist where it can be beneficial to a user for earbuds **110** to have communication channels with multiple audio sources. For example, earbuds **110** may receive audio from a computer (e.g., as audio source **120**) for a video conference, but the user may desire to allow his smartphone (e.g., as audio source **130**) to output notifications that are played instead of or over the audio for the video conference. As another example, a user may be listening to music via their smartphone (e.g., as audio source **120**), while listening to the music, the user may be in a public place that outputs auditory notifications via Bluetooth, such as flight notifications at an airport. A computerized system of the airport may function as audio source **130** which causes flight notifications to be output instead of or over the audio being streamed to earbuds **110** by audio source **120**.

[0043] Notably, audio source **130** may not be present in many embodiments or may only be intermittently present. Referring to the previous example, after leaving the airport (or perhaps disabling notifications), earbuds **110** may only receive audio from audio source **120**. Other similar examples exist. For example, referring to the first example, after conclusion of the video conference, earbuds **110** may only receive audio (e.g., the auditory notifications) from their smartphone. While the example of FIG. **1** illustrates two audio sources, it may be possible for earbuds **110** to receive audio from more than two audio sources. Earbuds **110** may be configured to prioritize and/or mix audio received concurrently from different audio sources.

[0044] For mono audio (e.g., a phone call, videoconference), the audio transmitted to one or each earbud of earbuds **110** from an audio source, such as audio source **120**, may be the same. For stereo audio (e.g., music playback, gaming), the audio transmitted to one or each earbud of earbuds **110** differs.

[0045] Turning to FIG. **1**B, data may be transmitted between an audio source **120** and a primary earbud such as earbud **110-1** of earbuds **110** and data may be transmitted between the primary earbud **110-1** and a secondary earbud such as earbud **110-2**. In a Bluetooth Classic scenario, data may be transmitted using a synchronous connection-oriented (SCO) channel or extended synchronous connection-oriented (eSCO) channel that may be present on link **123** between audio source **120** and primary earbud **110-1** and data may be transmitted using an ACL that may be present on link **150** between primary earbud **110-1** and secondary earbud **110-2**. In some embodiments, the data on link **123** and/or link **150** can include audio or voice data and control data transmitted in both directions. Control data as used herein generally refers to information pertaining to the link between the audio source **120** and primary earbud **110-1** and link between primary earbud **110-1** and the secondary earbud **110-2** (e.g., physical layer properties, timing information, encryption keys, power requirements, and the like). If audio is being transmitted from an earbud of earbuds **110** to audio source **120** (e.g., from a microphone of an earbud for a phone call), the SCO or eSCO link may be used and/or another SCO or eSCO link (not shown) may be used. Separate links may also respectively exist as part of wireless communications **141-1** through wireless communications **141**-N between audio source **120** and accessory devices **140-1** through **140**-N. In some embodiments, these links may be a link defined by the HID Profile under the Bluetooth core specification.

[0046] While one or more active communication channels are present between audio source **120** and earbuds **110**, one or more separate active communication channels can be present between audio source **120** and accessory devices **140**. Accessory device **140** can represent various forms of computerized devices capable of communicating and exchanging data using Bluetooth connections. One example of an accessory device included in accessory devices **140** is a wireless keyboard and another example of an accessory device included in accessory devices **140** is a wireless mouse. Other examples of accessory devices include human interface devices, printers, scanners, network devices, gaming devices, display assistants, and the like. In general, any computerized device that can communicate using Bluetooth can serve as an accessory device included in accessory devices **140**. In some embodiments, an accessory device included in accessory devices **140** can be used as and referred to as a peripheral and/or human interface device.

[0047] In some embodiments, communication between earbuds **110** and audio source **120** can be an acknowledgement, referred to as an ACK for short. An ACK can allow one of or both earbuds **110** to notify the audio source **120** that a Bluetooth packet was properly received from the audio source **120**. Similarly, an ACK can allow the audio source **120** to notify one of or both earbuds **110** that a Bluetooth packet was properly received from one of or both earbuds. An ACK and data packets between earbuds can be sent using the same radio used for Bluetooth communications. At a high level, when a packet addressed to a first earbud such as earbud **110-1** is properly received by the first earbud **110-1**, the first earbud **110-1** can transmit an ACK to the audio source **120**. This arrangement can prevent the audio source **120** from retransmitting the packet to the earbud **110-1** and/or can allow the earbud **110-1** to transmit the packet to the second earbud **110-2** if the second earbud **110-2** cannot intercept and/or otherwise acquire the packet transmitted from the audio source **120**. While an ACK is one form of communication that can occur between audio source **120** and earbuds **110**, other communications detailed herein between earbuds may not involve an ACK being transmitted.

[0048] FIG. **2** illustrates an embodiment of a block diagram of an audio system **200** that includes a pair of true wireless earbuds communicating with an audio source. Audio system **200** can represent an embodiment of audio system **100**A in which only a single audio source is present or audio system **100**B. Audio system **200** can include earbuds **110** and audio source **120**.

[0049] Referring to earbuds **110**, components of earbud **110-1** can include: antenna **210**; wireless communication interface **220**; processing system **230**; microphone **240**; and speaker **250**. Earbud **110-2** may have the same components. Antenna **210** can be used for receiving and transmitting Bluetooth-family communications, including BR/EDR, and LE (including LE Audio which uses LE). Wireless communication interface **220** can be implemented as a system on a chip (SOC). Wireless communication interface **220** can include a Bluetooth radio and componentry necessary to convert raw incoming data (e.g., audio data, other data) to Bluetooth packets for transmission via antenna **210**. Wireless communication interface **220** may also include componentry to enable one or more alternative or additional forms of wireless communication, both with an audio source and between earbuds. Processing system **230** may include one or more special-purpose or general-purpose processors. Such special-purpose processors may include processors that are specifically designed to perform the functions of the components detailed herein. Such special-purpose processors may be ASICs or FPGAs which are general-purpose components that are physically and electrically configured to perform the functions detailed herein. Such general-purpose processors may execute special-purpose software that is stored locally using one or more non-transitory processor-readable mediums, such as random-access memory (RAM), and/or flash memory. In some embodiments, processing system **230** and wireless communication interface **220** may be part of a same circuit or SOC.

[0050] In some earbuds, microphone **240** may be present. In some embodiments, each of earbuds **110** has a microphone. In other embodiments, only one of earbuds **110** has a microphone. In still other embodiments, no microphone may be present in either of earbuds **110**. Audio captured using the one or more microphones of earbuds **110** can be transmitted to audio source **120**. This audio, which can be referred to as "upstream" audio, may include voice, such as for use in a telephone call. video conference, gaming, etc. Various componentry (not illustrated) may be present between wireless communication interface **220**, processing system **230**, and microphone **240**, such as an analog to digital converter (ADC) and an amplifier.

[0051] Speaker **250**) converts received analog signals to audio. Various componentry (not illustrated) may be present between wireless communication interface **220**, processing system **230**, and speaker **250**, such as a digital to analog converter (DAC) and an amplifier.

[0052] Various components of earbud **110-1** are not illustrated. In addition to the ADC, DAC, and amplifiers previously mentioned, earbud **110-1** also includes a power storage component, such as one or more batteries, and associated componentry to allow for recharging of the power storage component. Also present is a housing and componentry to hold earbud **110-1** within a user's ear. One or more non-transitory processor readable mediums can be understood as present and accessible by wireless communication interface **220**, processing system **230**, or both. For instance, such mediums may be used for temporary storage of data (e.g., buffers) and storing data necessary for Bluetooth communication (e.g., encryption keys).

[0053] Audio source **120** can include: antenna **260**; wireless communication interface **270**; processing system **280**); and data storage **290**. Antenna **260** can be used for receiving and transmitting Bluetooth-family communications, including BR/EDR, and LE. Wireless communication interface **270**) can be implemented as a SOC. Wireless communication interface **270**) can include a Bluetooth radio and componentry necessary to convert raw incoming data (e.g., audio data. other data) to Bluetooth packets for transmission via antenna **260**. Wireless communication interface **270** can additionally or alternatively be used for one or more other forms of wireless communications. Processing system **280** may include one or more special-purpose or general-purpose processors. Such special-purpose processors may include processors that are specifically designed to perform the functions of the components detailed herein. Such special-purpose processors may be ASICs or FPGAs which are general-purpose components that are physically and electrically configured to perform the functions detailed herein. Such general-purpose processors may execute special-purpose software that is stored locally using one or more non-transitory processor-readable mediums via data storage **290**, which can include RAM, flash memory. a HDD and/or a SSD. In some embodiments. processing system **280** and wireless communication interface **270** may be part of a same circuit or SOC.

[0054] Audio source **120** can include various other components. For example, if audio source **120** is a smartphone, various components such as: one or more cameras, a display screen or touch screen, volume control buttons, other wireless communication interfaces can be present.

[0055] FIG. **3** illustrates an embodiment **300** of cross-body attenuation resulting in communication between an audio source and a first earbud experiencing more attenuation (or path loss) than communication between the audio source and the second earbud. In embodiment **300**, user **301** is holding audio source **120** in their left hand (that is, as illustrated, user **301** is facing out of the page). Bluetooth communications occur between audio source **120** and earbud **110-2** as indicated by link **122**; Bluetooth communications between audio source **120** and earbud **110-1** as indicated by link **121**.

[0056] Due to audio source **120** being in the user's left hand, link **121** with earbud **110-1**, which is in the user's right ear, results in wireless signals travelling through more of the user's body than link **122**. Therefore, more attenuation occurs in link **121** than link **122**. Accordingly, it is more likely that Bluetooth data packets exchanged between earbud **110-1** and audio source **120** may be not properly received than Bluetooth data packets exchanged between earbud **110-2** and audio source **120**.

[0057] Which earbud experiences more attenuation and/or interference in its communications with an audio source can vary based on the location of audio source **120**. Common places where user **301** may keep audio source **120** are: in a left hand; in a right hand; in a front left or right pocket, in a rear left or right pocket; on an arm band; in a left or right chest pocket; and on a surface or dock. Each of these locations can result in significantly different communication paths between each earbud and the antenna of the audio source and, thus, one earbud's communications can experience significantly higher interference or attenuation than the other earbud's communications.

[0058] FIG. **4** illustrates an embodiment of an audio system **400** in which true wireless earbuds communicate with each other in addition to communicating with an audio source. Earbud **110-1** can perform wireless communications using cross-link **410** with earbud **110-2** and, similarly, earbud **110-2** can perform wireless communications using cross-link **410** with earbud **110-1** in some embodiments. This communication can occur via a proprietary link specific to earbuds **110** and therefore can be outside of any Bluetooth family protocol specification. The path between earbuds **110**, when in use by user **301**, is predictable because the distance and the object through which the signals pass (the head of user **301**) remains constant. As detailed herein, the ability of earbuds **110** to communicate with each other can have significant advantages.

[0059] Cross-link **410** can use LE 2M, LE HDT (pending standardization), LE proprietary high data rate modes, classic BR/EDR, or some proprietary communication scheme. Therefore, while Bluetooth-compliant wireless communications occur between earbuds **110** and audio source **120**, communications directly between earbuds do not necessarily need to be compliant with Bluetooth or any other particular communication protocol.

[0060] In some embodiments, communication between earbuds **110** can be a cross-acknowledgement, referred to as a CrossACK for short. As detailed herein, "cross-" communications refer to wireless communications transmitted directly from a first earbud and received by a second earbud. A CrossACK can allow one of earbuds **110** to notify the other earbud of earbuds **110** that a Bluetooth packet was properly received from a source device. A CrossACK and data packets between earbuds can be sent using the same radio used for Bluetooth communications. At a high level, when a packet addressed to only a first earbud is not properly received by the first earbud, but is properly received by the second earbud, the second earbud can transmit a CrossACK to the first earbud. The first earbud may then request the packet be relayed to the first earbud from the second earbud. This arrangement prevents the first earbud from having to request retransmission from the source device and/or can allow the first earbud to obtain the data from the second earbud if transmissions from the audio source continue to fail.

[0061] While a CrossACK is one form of communication that can occur between earbuds **110**, other communications detailed herein between earbuds may not involve a CrossACK being transmitted.

[0062] FIGS. **5**A and **5**B illustrate embodiments **500**A, **500**B of communication between a call gateway **510** and true wireless earbuds, including first earbud **520-1** and second earbud **520-2**. during a voice call **530**. FIG. **6** illustrates an embodiment **600** of communication between the call gateway **510** and a keyboard **630** and mouse **640** during the voice call **530**. In some embodiments, the call gateway **510** can be the audio source **120**, the first and second earbuds **520-1**, **520-2** can be the true wireless earbuds **110**, and the keyboard **630** and mouse **640** can be included in the accessory devices **140** shown in FIG. **1**B. In some embodiments, the call gateway **510** can be connected to the first earbud **520-1**, the keyboard **630**, and the mouse **640** using a Bluetooth Classic connection and the first earbud **520-1** can be connected to the second earbud **520-2** using a Bluetooth LE connection. The foregoing arrangement is not intended to be limiting and other arrangements and short-range wireless technologies can be used.

[0063] In some embodiments, call gateway **510** can initiate the voice call **530** and a user such as **301** can participate in the voice call **530** using first and second earbuds **520-1**, **520-2**. During the voice call **530**, the call gateway **510** and the first earbud **520-1** can be connected using an eSCO link or channel. Similarly, during the voice call **530**, the call gateway **510** and the keyboard **630** and mouse **640**) can be connected using a link included the HID Profile. The eSCO link can include multiple connection intervals **532** (which can include connection intervals **532-1**, **532-2**, **532-3**, **532-4**, and so on). Each connection interval **532** can span a first length of time (e.g., 7.5 milliseconds). As shown in FIGS. **5**A, **5**B, and **6**, each connection interval **532** can be divided into multiple frames **634** (which can include frames **634-1**-**634-6**) and each frame **634** can be further divided into two slots **534** (which can include slots **534-1**-**534-12**). Each slot **534** can span a second length of time (e.g., 0.625 milliseconds) that is less than the first length of time. For example, a connection interval **532** that spans 7.5 milliseconds can include six frames with each framing spanning 1.25 milliseconds and including two slots each spanning 0.625 milliseconds.

[0064] Good link conditions, as used herein, refers to conditions in which the first earbud **520-1** properly receives a packet transmitted by the call gateway **510** during the voice call **530** and the second earbud **520-2** intercepts and/or otherwise acquires the transmitted packet. As such, as shown in FIG. **5**A, during the voice call **530** in which good link conditions exist, the first earbud **520-1** properly receives downstream packets **540** transmitted by the call gateway **510** and the second earbud **520-2** intercepts and/or otherwise acquires the transmitted downstream packets **540**. On the other hand, poor link conditions, as used herein, refers to conditions in which the first earbud **520-1** does not properly receive the packet transmitted by the call gateway **510** during the voice call **530** and/or the second earbud **520-2** cannot intercept and/or otherwise acquire the transmitted packet. As such, as shown in FIG. **5**B, during the voice call **530** in which poor link conditions exist, the first earbud **520-1** properly receives downstream packets **540** transmitted by the call gateway **510**, but the second earbud **520-2** cannot intercept and/or otherwise acquire the transmitted downstream packets **540**.

[0065] As shown in FIGS. **5**A and **5**B, for a given connection interval **532**, the call gateway **510** and the first earbud **520-1** can use the first slot **534** (e.g., slot **534-1** in connection interval **532-1**) for the call gateway **510** to transmit a downstream packet **540** to the first earbud **520-1** and use the second slot **534** (e.g., slot **534-2** in connection interval **532-1**) for the first earbud **520-1** to transmit an upstream packet **541** to the call gateway **510**. In some embodiments, for the given connection interval **532**, the call gateway **510** and the first earbud **520-1** can also use the third and fifth slots **534** (e.g., slots **534-3**, **534-5** in connection interval **532-1**) for the call gateway **510** to retransmit the downstream packet **540** to the first earbud **520-1**. Similarly, for the given connection interval **532**, the call gateway **510** and the first earbud **520-1** can also use fourth and sixth slots **534** (e.g., slots **534-4**, **534-6** in connection interval **532-1**) for the first earbud **520-1** to transmit an upstream packet **541** to the call gateway **510**. In some embodiments, the first earbud **520-1** can transmit an upstream packet **541** to the call gateway **510** whenever a downstream packet **540** is properly received by the first earbud **520-1** from the call gateway **510**. In other embodiments, the first earbud **520-1** can transmit an upstream packet **541** to the call gateway **510** once per connection interval **532**. In some embodiments, the upstream packets **541** transmitted by the first earbud **520-1** to the call gateway **510** include negative acknowledgments (referred to as a NACK for short). An upstream packet **541** that includes a NACK can serve to indicate to the call gateway **510** that the downstream packet **540** has not been properly received by the first earbud **520-1** and that the downstream packet **540** should be retransmitted to the first earbud **520-1** in the third and/or fifth slots **534**. Similarly, the call gateway **510** can treat any slot **534** reserved for an upstream packet **541** in which an upstream packet **541** is not received by the call gateway **510** in that slot **534** as an implicit NACK and retransmit the downstream packet **540** to the first earbud **520-1** in the next available slot **534** (e.g., the third and/or fifth slots). Downstream packets **540** that are retransmitted to the first earbud **520-1** after an upstream packet **541** has been properly received by the call gateway **510** can include an ACK to indicate to the first earbud **520-1** that the upstream packet **541** has been properly received by the call gateway **510** and that the upstream packet **541** does not need to be retransmitted by the first earbud **520-1** to the call gateway **510**. In this way, in poor link conditions, by reserving multiple slots **534** in each connection interval **532** during the voice call **530** for downstream and upstream packet transmission, the first earbud **520-1** and the second earbud **520-2** are provided with multiple opportunities to receive the downstream packet **540**) and the call gateway **510** is provided with multiple opportunities to receive the upstream packet **541** thereby improving voice call quality.

[0066] As discussed above, during the voice call **530**, the call gateway **510** and first earbud **520-1** can use up to six slots **534** (i.e., three frames **634**) for transmission of the downstream and upstream packets **540**, **541** in each connection interval **532** even if the downstream packet **540** is properly received by the first and second earbuds **520-1**, **520-2** in a first slot **534** and the upstream packet **541** is properly received by the call gateway **510** in a second slot **534**. When the call gateway **510** is connected to an accessory device during the voice call **530**, the call gateway **510** can also reserve/use one or more frames for polling and/or otherwise receiving packets from the accessory device at a predetermined polling rate. For example, when the call gateway **510** is connected to the keyboard **630**, the call gateway **510** can reserve/use one frame for polling the keyboard **630** at a predetermined rolling rate for the keyboard **630** such as one frame every 11.25 milliseconds. Similarly, when the call gateway **510** is connected to the mouse **640**, the call gateway **510** can reserve/use one frame for polling the mouse **640** at a predetermined rolling rate for the mouse **640** such as two frames every 11.25 milliseconds. Also, in order to discover new devices, the call gateway **510** can reserve/use three frames for scanning for new devices at a predetermined scanning rate such as three frames every 22.5 milliseconds. In some embodiments, the polling rates can be determined by the type of accessory device (e.g., a watch, heart rate monitor) that is connected to the call gateway **510**. In other embodiments, the polling rates can be determined based on the HID Profile.

[0067] In some embodiments, because there is a potential for overlap for traffic between the call gateway **510**, the first earbud **520-1**, the accessory device(s), and the scanning, the call gateway **510** can implement a traffic prioritization scheme. For example, the call gateway **510** can prioritize traffic between the call gateway **510** and the first earbud **520-1** over the traffic between the call gateway **510** and the accessory device(s) (e.g., the keyboard **630** and mouse **640**) and can prioritize scanning for new devices over traffic between the call gateway **510** and the accessory device(s). However, during the voice call **530**, implementing a prioritization scheme such as the one described above can increase the bandwidth utilization at the call gateway **510** resulting in polling the accessory device(s) at a reduced rate and/or skipping polling of an accessory device altogether. When the polling rate of an accessory device is reduced and/or the accessory device is not polled, accessory device lag and/or non-responsiveness can occur. For example, as shown in FIG. **6**, the call gateway **510** can use the first three frames in each connection interval **532** for traffic **660** between the call gateway **510** and the first earbud **520-1** and the subsequent three frames in each connection interval **532** for other traffic **664**, **666** such as polling the keyboard **630** or mouse **640** and performing scans to discover new devices. In this scheme, the call gateway **510** only uses two frames every 22.5 milliseconds for polling the mouse **540** and does not use any frames for polling the keyboard **630**. As such, a user may experience lag or non-responsiveness when using the keyboard **530** during the voice call **530** in which the call gateway **510** is connected to the first earbud **520-1**.

[0068] To overcome the foregoing challenges and others, in some embodiments. an ACK can be included in upstream packets transmitted by the first earbud **520-1** to the call gateway **510**. An upstream packet that includes an ACK can serve to indicate to the call gateway **510** that the downstream packet **540** has been properly received by the first earbud **520-1** and that the downstream packet **540**) does not need to be retransmitted to the first earbud **520-1** in another slot **534** (e.g., the third and/or fifth slots). The call gateway **510** can then use other reserved slots/frames in the connection interval **532** for other activities (e.g., polling accessory devices and/or performing scans for new devices) thereby reducing bandwidth utilization at the call gateway **510** during the voice call **530**.

[0069] FIG. **7**A illustrates an embodiment **700**A of communication between the call gateway **510** and true wireless earbuds, including first earbud **520-1** and second earbud **520-2**, in which, during the voice call **530**, the first earbud **520-1** transmits an upstream packet **741** that includes an ACK to the call gateway **510** in response to properly receiving a downstream packet **540** transmitted by the call gateway **510** (e.g., in the first slot **534-1** in the first connection interval **532-1**). The call gateway **510** can treat the upstream packet **741** that includes the ACK as a confirmation that the downstream packet **540** transmitted to the first earbud **520-1** has been properly received by the first earbud **520-1** in a given connection interval **532** and that the downstream packet **540** does not need to be retransmitted in other reserved slots/frames in the given connection interval **532** (e.g., does not need to be retransmitted in the third and fifth slots) to the first earbud **520-1**. Because a properly received downstream packet **540**) does not need to be retransmitted in other reserved slots/frames, the call gateway **510** can then use the other reserved slots/frames in the connection interval **532** for other traffic (e.g., polling accessory devices and/or performing scans for new devices).

[0070] FIG. **7**B. which illustrates another embodiment **700**B of communication between the call gateway **510** and the keyboard **630** and mouse **640** in which, during the voice call **530**, only a single frame in each connection interval **532** is used for traffic **660** between the call gateway **510** and the first earbud **520-1**. As shown in FIG. **7**B, when only a single frame in each connection interval **532** is used for traffic **660** between the call gateway **510** and the first earbud **520-1**, other frames in each connection interval **532** can be reserved/used for other traffic **662**, **664**, and **666** such as polling the keyboard **630** or mouse **640** and/or performing scans to discover new devices. In this scheme, the call gateway **510** can poll the keyboard **630** once and the mouse **640** four times every 22.5 milliseconds. As such, during the voice call **530** in which the call gateway **510** is connected to the first earbud **520-1**. bandwidth utilization at the call gateway **510** during the voice call **530** can be decreased while reducing lag and increasing responsivity of accessory devices also connected to the call gateway **510**.

[0071] In the foregoing scheme, the second earbud **520-2** is provided with just a single opportunity to intercept and/or otherwise acquire the downstream packet **540** transmitted by the call gateway **510** in each connection interval **534**. As described above, in poor link conditions, the second earbud **520-2** may not intercept and/or otherwise acquire the transmitted packet. To ensure the second earbud **520-2** acquires the transmitted packet in a given connection interval **532** in the foregoing scheme, the first earbud **520-1** can transmit a data packet corresponding to a properly received downstream packet **540** in the given connection interval **532** to the second earbud **520-2** and the second earbud **520-2** can transmit an ACK in response to properly receiving the data packet from the first earbud **520-1**.

[0072] In some embodiments, upon properly receiving the downstream packet **540** from the call gateway **510**, the first earbud **520-1** can decode the downstream packet **540** into audio or voice data. The audio or voice data can include audio or voice data for an audio channel associated with the first earbud **520-1** and/or audio or voice data for an audio channel associated with the second earbud **520-1**. In some embodiments, the audio or voice data can include audio or voice for an audio channel associated with both the first and second earbuds **520-1**, **520-2**. Upon decoding the downstream packet **540**), the first earbud **520-1** can generate data packets from the audio or voice data. In some embodiments, the first earbud **520-1** generates the data packets by dividing the audio or voice data into pieces of audio or voice data and the pieces of audio or voice data are transmitted from the first earbud **520-1** to the second earbud **520-2** as the data packets. In other embodiments, the first earbud **520-1** can generate the data packets by dividing the audio or voice data into pieces of audio or voice data and encrypting and/or packetizing the pieces of audio or voice data and the encrypted and packetized audio or voice data is transmitted from the first earbud **520-1** to the second earbud **520-2** as the data packets.

[0073] In some embodiments, for a given connection interval **532**, the first and second earbuds **520-1**, **520-2** can reserve/use two slots in the given connection interval **532** for first earbud **520-1** to transmit a data packet corresponding to the properly received downstream packet **540**) to the second earbud **520-2** and for the second earbud **520-2** to transmit an ACK to the first earbud **520-1** in response to properly receiving the data packet from the first earbud **520-1**. For example, as shown in FIG. **7**A, in a given connection interval **532**, the first and second earbuds **520-1**, **520-2** can reserve/use the seventh and eighths slots (e.g., slots **534-7**, **534-8** in the first connection interval **532-1**) for the first earbud **520-1** to transmit a data packet **540** corresponding to the properly received downstream packet **540** to the second earbud **520-2** and for the second earbud **520-2** to transmit an ACK **751** to the first earbud **520-1** in response to properly receiving the data packet from the first earbud **520-1**. In some embodiments, prior to forwarding the properly received downstream packet **540**, the first earbud **520-1** can poll and/or otherwise handshake with the second earbud **520-2** to determine whether the second earbud **520-1** properly intercepted and/otherwise acquired the downstream packet **540** transmitted by the call gateway **510**. The first earbud **520-1** can transmit the data packet **540** corresponding to the properly received downstream packet **540**) to the second earbud **520-2** if it is determined that the second earbud **520-2** did not intercept and/or was otherwise unable to properly acquire the downstream packet **540** transmitted by the call gateway **510**. In this way, because the second earbud **520-2** is provided with the opportunity to acquire the downstream packet **540** from either the call gateway **510** and/or the first earbud **520-1**, voice call quality during the voice call can be improved even in poor link conditions along with reducing bandwidth utilization at the call gateway **510**.

[0074] The foregoing scheme is not intended to be limiting and other arrangements such as a rotating ACK scheme can be implemented. In a rotating ACK scheme, an ACK can be periodically included in upstream packets transmitted by the first earbud **520-1** to the call gateway **510**. In some embodiments, an ACK can be included in upstream packets transmitted by the first earbud **520-1** in every other connection interval **532**, every third connection interval **532**, every fourth connection interval **532**, and so on. In connection intervals **532** in which an ACK is included in upstream packets transmitted by the first earbud **520-1**, only a single frame in each connection interval **532** can be used for traffic between the call gateway **510** and the first earbud **520-1**. In connection intervals **532** in which upstream packets transmitted by the first earbud **520-1** include a NACK or the first earbud **520-1** does not transmit an upstream packet, multiples frames in each connection interval **532** can be used for traffic between the call gateway **510** and the first earbud **520-1**.

[0075] FIG. **8**A illustrates an embodiment **800**A of communication between the call gateway **510** and true wireless earbuds, including first earbud **520-1** and second earbud **520-2**, in which, during the voice call **530**, the first earbud **520-1** periodically transmits an upstream packet **741** that includes an ACK to the call gateway **510** in response to properly receiving a downstream packet **540** transmitted by the call gateway **510** (e.g., in the first slot **534**). In some embodiments, the voice call **530** can include multiple windows (not shown). Each window of the voice call **530** can span a length of time (e.g., 67.5 milliseconds). In some embodiments, for each window of the voice call **530**, the first earbud **520-1** can transmit an upstream packet **741** that includes an ACK to the call gateway **510** in response to properly receiving a downstream **540** transmitted by the call gateway **510** in the first connection interval **532** of the respective window and in every fourth connection interval **532** thereafter of the respective window. For example, for a given window, the first earbud **520-1** can transmit an upstream packet **741** that includes an ACK to the call gateway **510** in the first connection interval **532** of the given window, in the fifth connection interval **532** of the given window, and in the ninth connection interval **532** of the given window. As shown in FIG. **8**A, in the first connection interval **532**, the first earbud **520-1** transmits an upstream packet **741** that includes an ACK to the call gateway **510** in response to properly receiving a downstream packet **540** transmitted by the call gateway **510** (e.g., in the first slot **534**). As further shown in FIG. **8**A. in the second connection interval **532**, the first earbud **520-1** transmits an upstream packet **541** that includes a NACK to the call gateway **510** in response to properly receiving a downstream packet **540** transmitted by the call gateway **510**. In this way, voice call quality can be improved while balancing bandwidth utilization in the call gateway **510** during the voice call **530**.

[0076] FIG. **8**B-**8**D, which illustrates an embodiment **800**B of communication between the call gateway **510** and the keyboard **630** and mouse **640** in which, during the voice call **530**, only a single frame in the first connection interval **532** and in every fourth connection interval **532** thereafter is reserved/used for traffic **660** between the call gateway **510** and the first earbud **520-1** in a given window of the voice call **530**. As shown in FIGS. **8**B-**8**D, by reserving/using a single frame for traffic **660** between the call gateway **510** and the first earbud **520-1** in the first connection interval **532** and in every fourth connection interval **532** thereafter in a given window, frames in the respective connection intervals **532** can be reserved/used for other traffic **662**, **664**, and **666** such as polling the keyboard **630** or mouse **640** and/or performing scans to discover new devices. Similarly, by reserving/using multiple frames for traffic **660** between the call gateway **510** and the first earbud **520-1** in the remaining connection intervals **532**, other frames in the remaining connection intervals **532** can be reserved/used for retransmission of the downstream packets **540** and upstream packets **741**. In this scheme, the call gateway **510** can poll the keyboard **630** at least once every 67.5 milliseconds and the mouse **640** at least once every 22.5 milliseconds. As such, during the voice call **530** in which the call gateway **510** is connected to the first earbud **520-1**, bandwidth utilization at the call gateway

510 during the voice call **530** can be decreased while reducing lag and increasing responsivity of accessory devices also connected to the call gateway **510**.

[0077] FIG. **9** illustrates an embodiment of a method **900** corresponding to the embodiments of FIG. **7**A and **7**B. The processing depicted in FIG. **9** may be implemented in software (e.g., code, instructions, program) executed by a processing system such as a processing system of the call gateway **510** and/or the first earbud **520-1**. The software may be stored on a non-transitory computer-readable storage medium (e.g., a memory device). The method **900** is intended to be illustrative and non-limiting. For example, although FIG. **9** depicts the various processing steps occurring in a particular sequence or order, in other embodiments, the steps may be performed in some different order or some steps may also be performed in parallel.

[0078] At block **902**, a downstream packet is received by a first earbud of a set of earbuds from a device using a first wireless link in a connection interval of a plurality of connection intervals. In some embodiments, the connection interval includes a plurality of slots and the downstream packet is received in a first slot of the plurality of slots. In some embodiments, the first wireless link is a Bluetooth Basic Rate/Enhanced Data Rate (Bluetooth BR/EDR) link.

[0079] At block **904**, an upstream packet is transmitted from the first earbud to the device using the first wireless link in the connection interval. The upstream packet includes an indication that the downstream packet was properly received. In some embodiments, the upstream packet also includes voice information of a user participating in a voice call using the set of earbuds. In some embodiments, the upstream packet is transmitted in a second slot of the plurality of slots, where the second slot is adjacent to the first slot in the connection interval.

[0080] At block **906**, a determination is made by the first earbud and a second earbud of the set of earbuds whether the second earbud has acquired the downstream packet in the connection interval. In response to determining that the second earbud has acquired the downstream packet in the connection interval, the method reverts to block **902** in which another downstream packet is received by the first earbud from the device using the first wireless link in another connection interval of the plurality of connection intervals. In response to determining that the second earbud has not acquired the downstream packet in the connection interval, the method proceeds to block **908**.

[0081] At block **908**, a data packet corresponding to the downstream packet is transmitted from the first earbud to the second earbud using a second wireless link. In some embodiments, the second wireless link is a Bluetooth Low Energy Link.

[0082] At block **910**, a check is made whether the voice call has ended. In response to determining that the voice call has not ended, the method reverts to block **902** in which another downstream packet is received from the device using the first wireless link in another connection interval of the plurality of connection intervals. In response to determining that the voice call has ended, the method ends.

[0083] FIG. **10** illustrates an embodiment of a method **1000** corresponding to the embodiments of FIGS. **8**A-**8**D. The processing depicted in FIG. **10** may be implemented in software (e.g., code, instructions, program) executed by a processing system such as a processing system of the call gateway **510** and/or the first earbud **520-1**. The software may be stored on a non-transitory computer-readable storage medium (e.g., a memory device). The method **1000** is intended to be illustrative and non-limiting For example, although FIG. **10** depicts the various processing steps occurring in a particular sequence or order, in other embodiments, the steps may be performed in some different order or some steps may also be performed in parallel.

[0084] At block **1002**, a plurality of downstream packets is received by a first earbud of a set of earbuds from a device using a first wireless link in a set of connection intervals of a plurality of connection intervals. In some embodiments, each downstream packet of the plurality of downstream packets is received in a first slot of a plurality of slots of each connection interval of the set of connection intervals. In some embodiments, the first wireless link is a Bluetooth Basic Rate/Enhanced Data Rate (Bluetooth BR/EDR) link.

[0085] At block **1004**, a plurality of upstream packets is transmitted from the first earbud to the device using the first wireless link in the set of connection intervals. In some embodiments, each upstream packet of the plurality of upstream packets is transmitted in a second slot of the plurality of slots of each connection interval of the set of connection intervals wherein the second slot of a respective connection interval of the set of connection intervals is adjacent to the first slot of the respective connection interval. In some embodiments, a first upstream packet of the plurality of upstream packets includes an indication that a first downstream packet of the plurality of downstream packets was properly received by the first earbud. In some embodiments, a second upstream packet of the plurality of upstream packets includes an indication that a second downstream packet of the plurality of downstream packets was not properly received by the first earbud. In some embodiments, each first upstream packet of the plurality of first upstream packets includes voice information of a user participating in a voice call using the set of earbuds.

[0086] At block **1006**, a determination is made by the first earbud and a second earbud of the set of earbuds that the second earbud has not acquired the first downstream packet.

[0087] At block **1008**, a data packet corresponding to the first downstream packet is transmitted from the first earbud to the second earbud using a second wireless link. In some embodiments, the second wireless link is a Bluetooth Low Energy link. In some embodiments, the data packet corresponding to the first downstream packet is transmitted from the first earbud to the second earbud using the second wireless link in response to determining that the second earbud has not acquired the first downstream packet.

[0088] The systems and methods of the present disclosure may be implemented using hardware, software, firmware, or a combination thereof and may be implemented in one or more computer systems or other processing systems. Some embodiments of the present disclosure include a system including a processing system that includes one or more processors. In some embodiments, the system includes a non-transitory computer readable storage medium containing instructions which, when executed on the one or more processors, cause the system and/or the one or more processors to perform part or all of one or more methods and/or part or all of one or more processes disclosed herein. Some embodiments of the present disclosure include a computer-program product tangibly embodied in a non-transitory machine-readable storage medium, including instructions configured to cause the system and/or the one or more processors to perform part or all of one or more methods and/or part or all of one or more processes disclosed herein.

[0089] The terms and expressions which have been employed are used as terms of description and not of limitation, and there is no intention in the use of such terms and expressions of excluding any equivalents of the features shown and described or portions thereof, but it is recognized that various modifications are possible within the scope of the invention claimed. Thus, it should be understood that although the present invention as claimed has been specifically disclosed by embodiments and optional features, modification, and variation of the concepts herein disclosed may be resorted to by those skilled in the art, and that such modifications and variations are considered to be within the scope of this invention as defined by the appended claims.

[0090] Specific details are given in the following description to provide a thorough understanding of the embodiments. However, it will be understood that the embodiments may be practiced without these specific details. For example, circuits, systems, networks, processes, and other components may be shown as components in block diagram form in order not to obscure the embodiments in unnecessary detail. In other instances, well-known circuits, processes, algorithms, structures, and techniques may be shown without unnecessary detail in order to avoid obscuring the embodiments.

[0091] The above description of certain examples, including illustrated examples, has been presented only for the purpose of illustration and description and is not intended to be exhaustive or to limit the disclosure to the precise forms disclosed. Modifications, adaptations, and uses thereof will be apparent to those skilled in the art without departing from the scope of the disclosure. For instance, any examples described herein can be combined with any other examples.

What is claimed is:

1. A method for controlling a set of earbuds, the method comprising:

receiving, by a first earbud of the set of earbuds from a device using a first wireless link in a set of connection intervals of a plurality of connection intervals, a plurality of downstream packets; and

transmitting, from the first earbud to the device using the first wireless link in the set of connection intervals, a plurality of upstream packets, wherein a first upstream packet of the plurality of upstream packets comprises an indication that a first downstream packet of the plurality of downstream packets was properly received by the first earbud, and wherein a second upstream packet of the plurality of upstream packets comprises an indication that a second downstream packet of the plurality of downstream packets was not properly received by the first earbud.

2. The method of claim **1**, wherein the first wireless link is a Bluetooth Basic Rate/Enhanced Data Rate (Bluetooth BR/EDR) link.

3. The method of claim **1**, further comprising:

determining, by the first earbud and a second earbud of the set of earbuds, that the second earbud has not acquired the first downstream packet; and

in response to determining that the second earbud has not acquired the first downstream packet, transmitting, from the first earbud to the second earbud using a second wireless link, a data packet corresponding to the first downstream packet.

4. The method of claim **3**, wherein the second wireless link is a Bluetooth Low Energy link.

5. The method of claim **1**, wherein each upstream packet of the plurality of upstream packets comprises voice information of a user participating in a voice call using the set of earbuds.

6. The method of claim **1**, wherein each downstream packet of the plurality of downstream packets is received in a first slot of a plurality of slots of each connection interval of the set of connection intervals.

7. The method of claim **6**, wherein each upstream packet of the plurality of upstream packets is transmitted in a second slot of the plurality of slots of each connection interval of the set of connection intervals, the second slot of a respective connection interval of the set of connection intervals adjacent to the first slot of the respective connection interval.

8. A system comprising:

a processing system; and

a computer-readable medium storing instructions which, when executed by the processing system, cause the system to perform a method comprising:

receiving, by a first earbud of a set of earbuds from a device using a first wireless link in a set of connection intervals of a plurality of connection intervals, a plurality of downstream packets; and

transmitting, from the first earbud to the device using the first wireless link in the set of connection intervals, a plurality of upstream packets, wherein a first upstream packet of the plurality of upstream packets comprises an indication that a first downstream packet of the plurality of downstream packets was properly received by the first earbud, and wherein a second upstream packet of the plurality of upstream packets comprises an indication that a second downstream packet of the plurality of downstream packets was not properly received by the first earbud.

9. The system of claim **8**, wherein the first wireless link is a Bluetooth Basic Rate/Enhanced Data Rate (Bluetooth BR/EDR) link.

10. The system of claim **8**, further comprising:

determining, by the first earbud and a second earbud of the set of earbuds, that the second earbud has not acquired the first downstream packet; and

in response to determining that the second earbud has not acquired the first downstream packet, transmitting, from the first earbud to the second earbud using a second wireless link, a data packet corresponding to the first downstream packet.

11. The system of claim **10**, wherein the second wireless link is a Bluetooth Low Energy link.

12. The system of claim **8**, wherein each upstream packet of the plurality of upstream packets comprises voice information of a user participating in a voice call using the set of earbuds.

13. The system of claim **8**, wherein each downstream packet of the plurality of downstream packets is received in a first slot of a plurality of slots of each connection interval of the set of connection intervals.

14. The system of claim **13**, wherein each upstream packet of the plurality of upstream packets is transmitted in a second slot of the plurality of slots of each connection interval of the set of connection intervals, the second slot of a respective connection interval of the set of connection intervals adjacent to the first slot of the respective connection interval.

15. A non-transitory computer-readable media storing instructions which, when executed by a processing system of an earbud, cause the earbud to perform a method comprising:

receiving, by a first earbud of a set of earbuds from a device using a first wireless link in a set of connection intervals of a plurality of connection intervals, a plurality of downstream packets; and

transmitting, from the first earbud to the device using the first wireless link in the set of connection intervals, a plurality of upstream packets, wherein a first upstream packet of the plurality of upstream packets comprises an indication that a first downstream packet of the plurality of downstream packets was properly received by the first earbud, and wherein a second upstream packet of the plurality of upstream packets comprises an indication that a second downstream packet of the plurality of downstream packets was not properly received by the first earbud.

16. The non-transitory computer-readable medium of claim **15**, wherein the first wireless link is a Bluetooth Basic Rate/Enhanced Data Rate (Bluetooth BR/EDR) link.

17. The non-transitory computer-readable medium of claim **15**, further comprising:

determining, by the first earbud and a second earbud of the set of earbuds, that the second earbud has not acquired the first downstream packet; and

in response to determining that the second earbud has not acquired the first downstream packet, transmitting, from the first earbud to the second earbud using a second wireless link, a data packet corresponding to the first downstream packet.

18. The non-transitory computer-readable medium of claim **15**, wherein each upstream packet of the plurality of upstream packets comprises voice information of a user participating in a voice call using the set of earbuds.

19. The non-transitory computer-readable medium of claim **15**, wherein each downstream packet of the plurality of downstream packets is received in a first slot of a plurality of slots of each connection interval of the set of connection intervals.

20. The non-transitory computer-readable medium of claim **19**, wherein each upstream packet of the plurality of upstream packets is transmitted in a second slot of the plurality of slots of each connection interval of the set of connection intervals, the second slot of a respective connection interval of the set of connection intervals adjacent to the first slot of the respective connection interval.

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