



US009883298B2

(12) **United States Patent**
Solum

(10) **Patent No.:** **US 9,883,298 B2**
(45) **Date of Patent:** ***Jan. 30, 2018**

(54) **METHOD AND APPARATUS FOR COMMUNICATION BETWEEN HEARING ASSISTANCE DEVICES IN A BLUETOOTH NETWORK**

(58) **Field of Classification Search**
CPC .. H04R 25/456; H04R 25/502; H04R 25/505; H04R 25/552; H04R 25/554
USPC 381/312, 314, 315, 327, 328, 330
See application file for complete search history.

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(56) **References Cited**

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U.S. PATENT DOCUMENTS

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6,694,143 B1 2/2004 Beamish et al.
7,359,950 B2 4/2008 Choi et al.
7,496,065 B2 2/2009 Anjum et al.
7,688,991 B2 3/2010 Baechler
(Continued)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

FOREIGN PATENT DOCUMENTS

EP 2200344 A2 6/2010
EP 2439960 A1 4/2012
EP 2456234 A1 5/2012

(21) Appl. No.: **15/362,455**

OTHER PUBLICATIONS

(22) Filed: **Nov. 28, 2016**

"U.S. Appl. No. 13/937,013, Notice of Allowance dated Jan. 5, 2015", 7 pgs.

(65) **Prior Publication Data**

(Continued)

US 2017/0171673 A1 Jun. 15, 2017

Related U.S. Application Data

Primary Examiner — Brian Ensey

(63) Continuation of application No. 14/846,426, filed on Sep. 4, 2015, now Pat. No. 9,510,113, which is a continuation of application No. 13/937,013, filed on Jul. 8, 2013, now Pat. No. 9,131,322.

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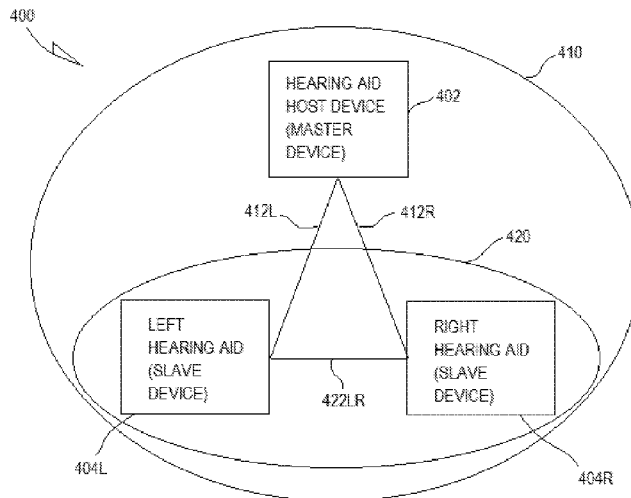
(51) **Int. Cl.**
H04R 25/00 (2006.01)
H04W 4/00 (2009.01)

(57) **ABSTRACT**

(52) **U.S. Cl.**
CPC **H04R 25/554** (2013.01); **H04R 25/558** (2013.01); **H04W 4/008** (2013.01); **H04R 2225/55** (2013.01)

A hearing assistance system provides for wireless communication between hearing assistance devices that are in a Bluetooth connection with a host device. In various embodiments, during a Bluetooth connection interval, one or more time slots are used for communication between the host device and one or more of the hearing assistance devices, while one or more additional time slots are reserved for communication between the hearing assistance devices.

20 Claims, 6 Drawing Sheets



(56)

References Cited

U.S. PATENT DOCUMENTS

8,081,787	B2 *	12/2011	Haenggi	H04R 25/554
				381/312
8,194,902	B2	6/2012	Pedersen	
8,229,146	B2	7/2012	Nielsen	
8,942,396	B2 *	1/2015	Popovski	H04L 1/18
				381/312
9,131,322	B2	9/2015	Solum	
9,510,113	B2	11/2016	Solum	
2004/0013280	A1	1/2004	Niederdrank	
2006/0067550	A1	3/2006	Puder et al.	
2012/0121095	A1	5/2012	Popovski et al.	
2015/0010179	A1	1/2015	Solum et al.	
2016/0073204	A1	3/2016	Solum	

OTHER PUBLICATIONS

- "U.S. Appl. No. 13/937,013, Notice of Allowance dated May 5, 2015", 6 pgs.
- "U.S. Appl. No. 14/846,426, Non Final Office Action dated Feb. 10, 2016", 10 pgs.
- "U.S. Appl. No. 14/846,426, Notice of Allowance dated Jul. 28, 2016", 6 pgs.
- "U.S. Appl. No. 14/846,426, Preliminary Amendment filed Dec. 4, 2015", 6 pgs.
- "U.S. Appl. No. 14/846,426, Response filed May 10, 2016 to Non Final Office Action dated Feb. 10, 2016", 10 pgs.
- "European Application Serial No. 14175910.0, Extended European Search Report dated Nov. 12, 2014", 7 pgs.
- "European Application Serial No. 14175910.0, Communication Pursuant to Article 94(3) EPC dated Sep. 18, 2017", 5 pgs.

* cited by examiner

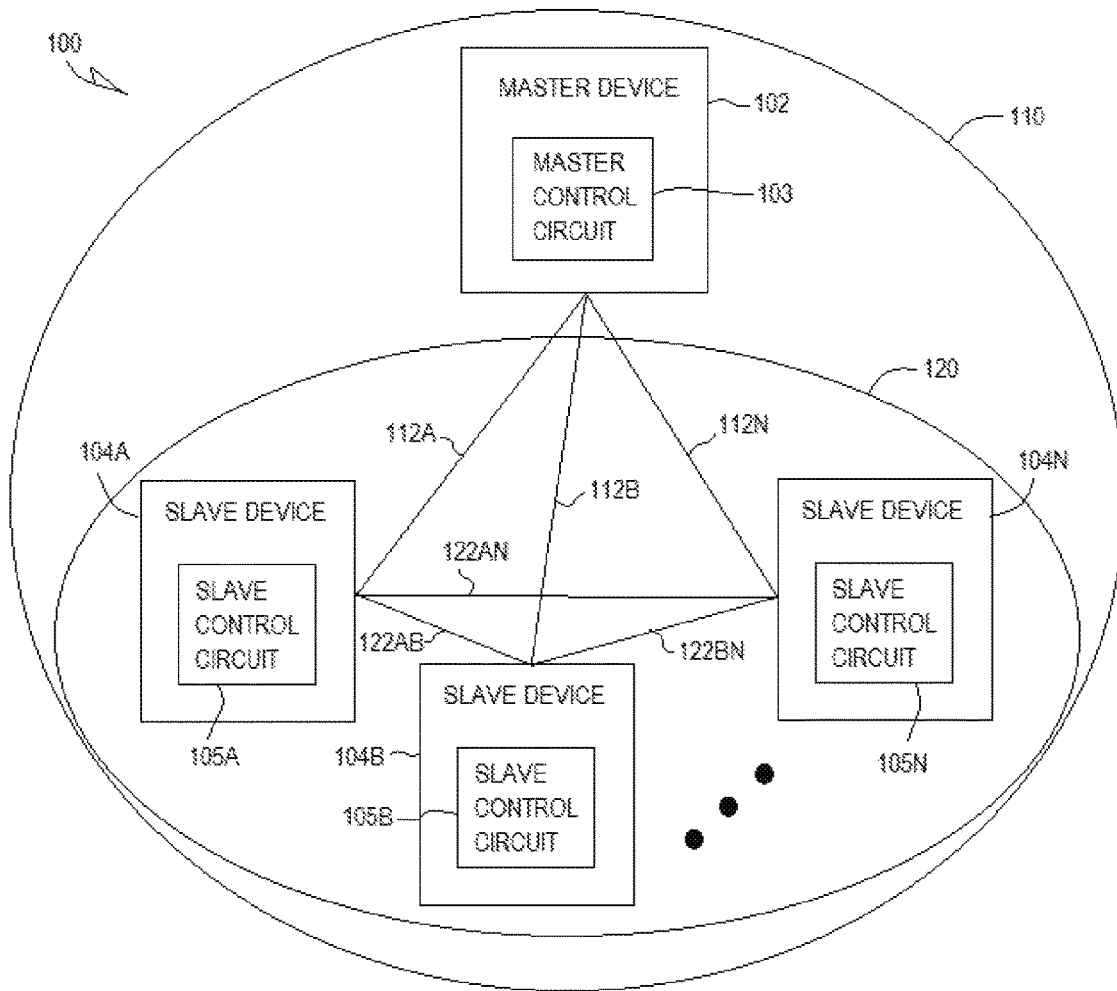


Fig. 1

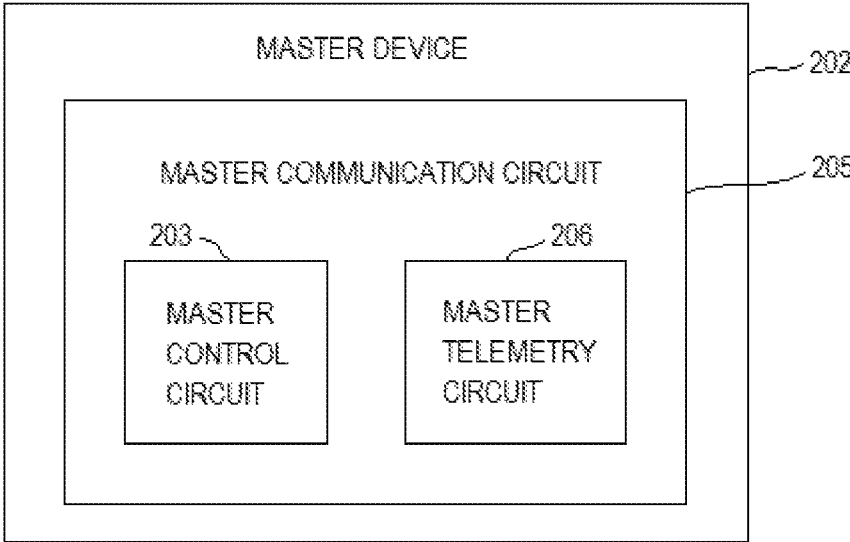


Fig. 2

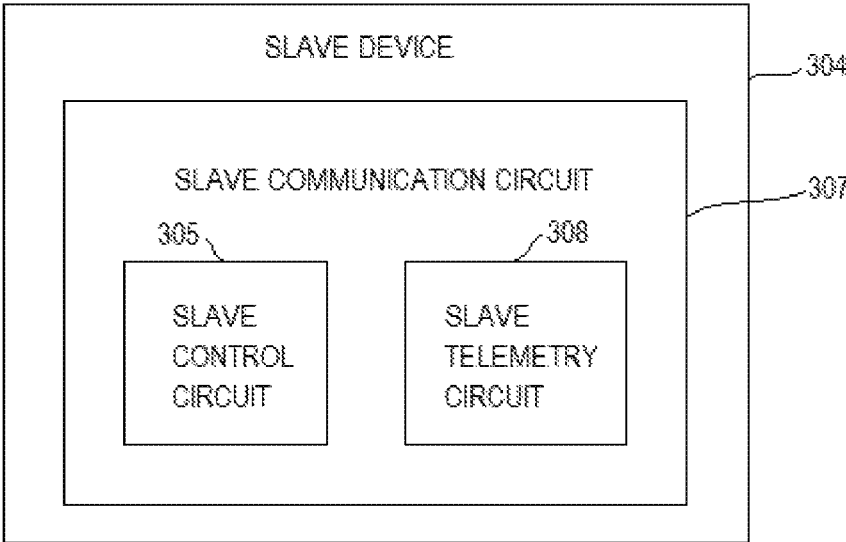


Fig. 3

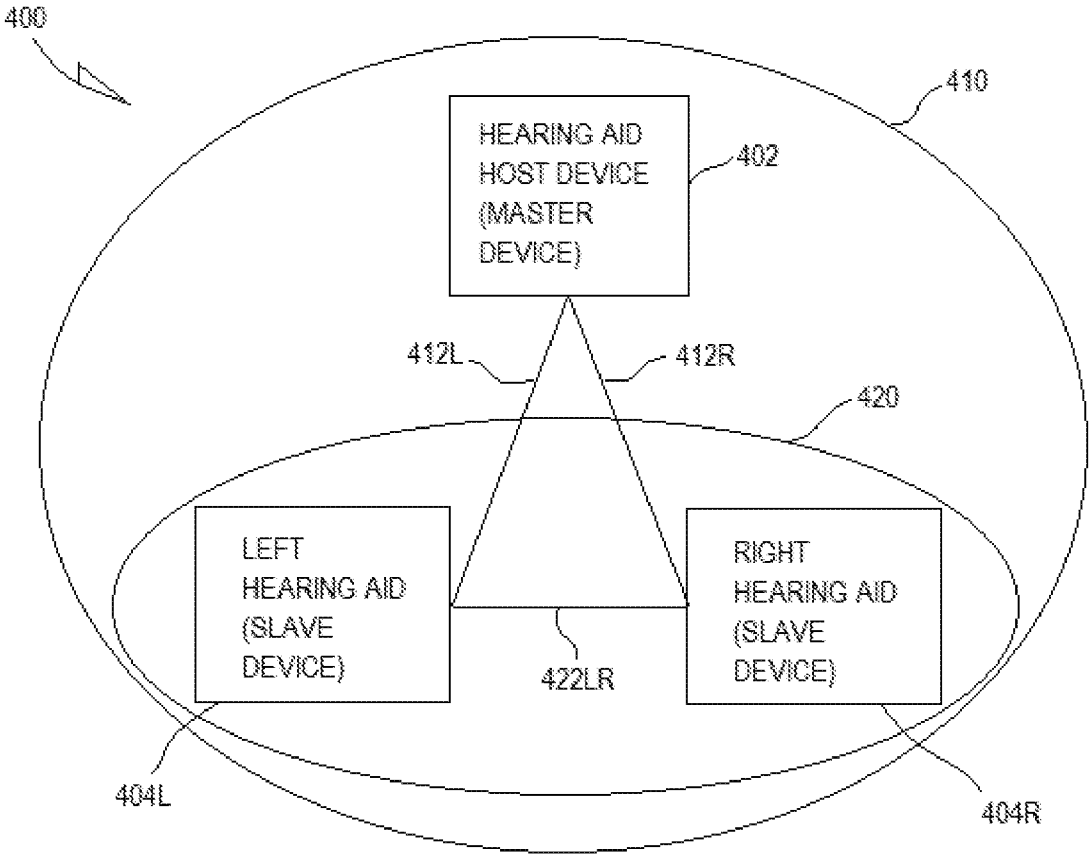


Fig. 4

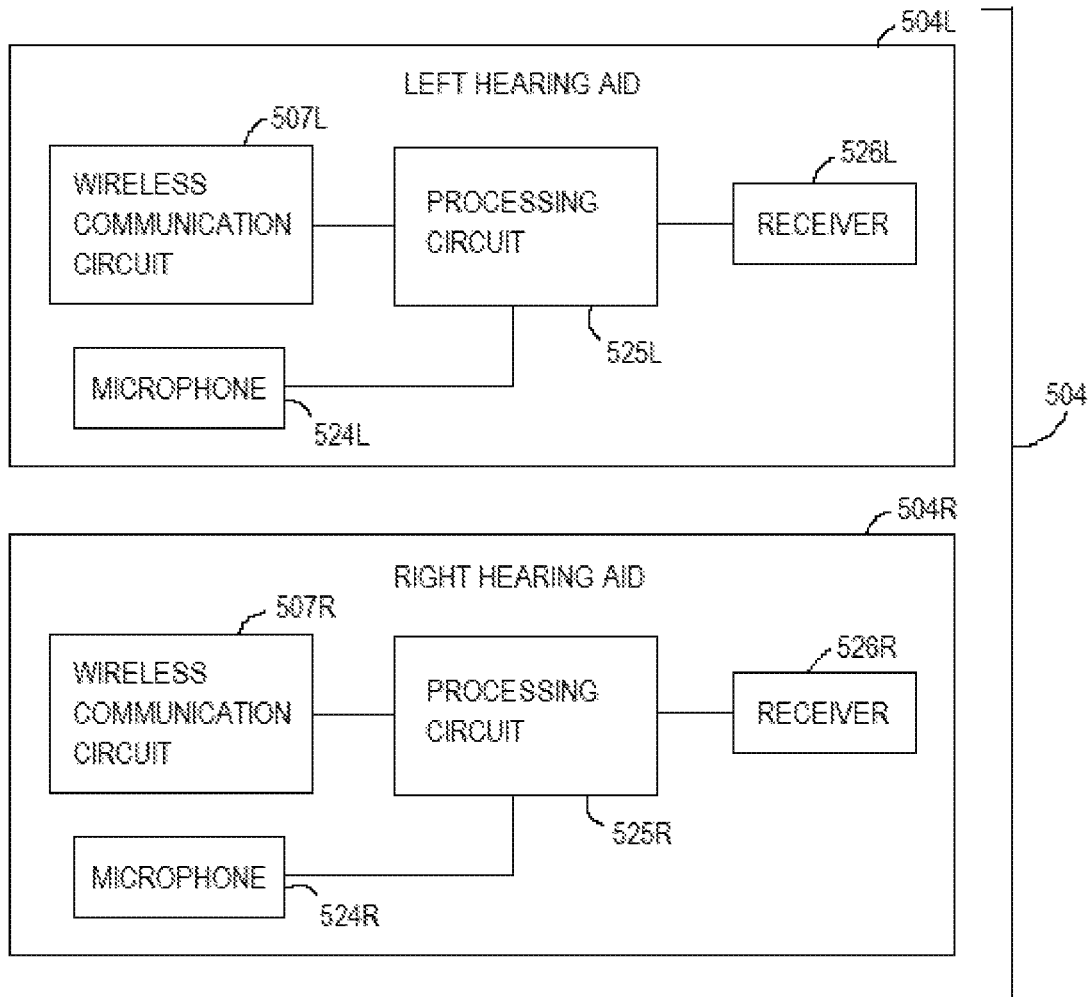


Fig. 5

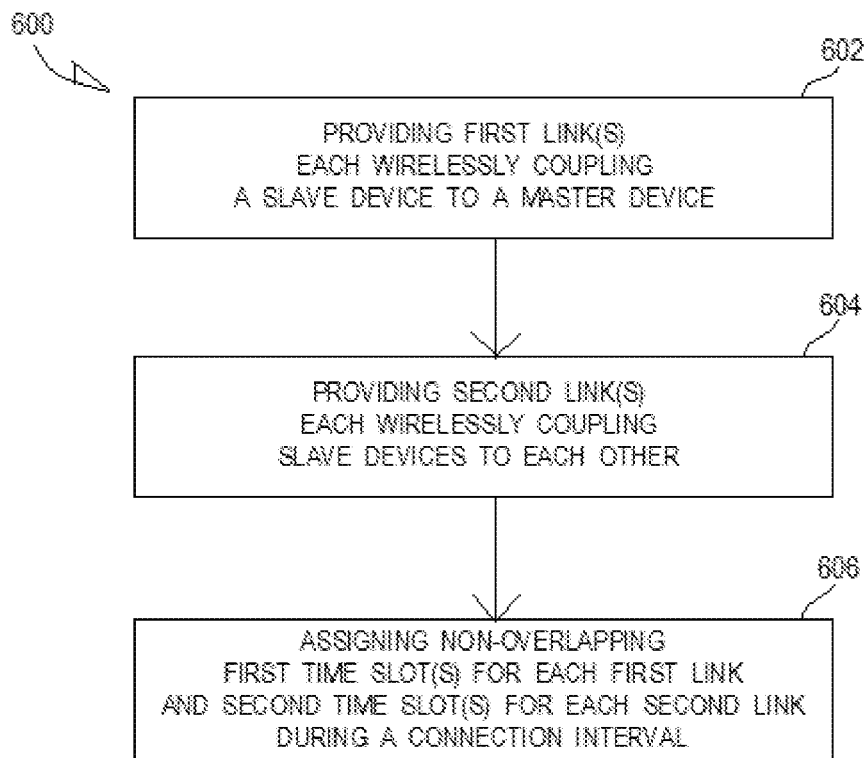


Fig. 6

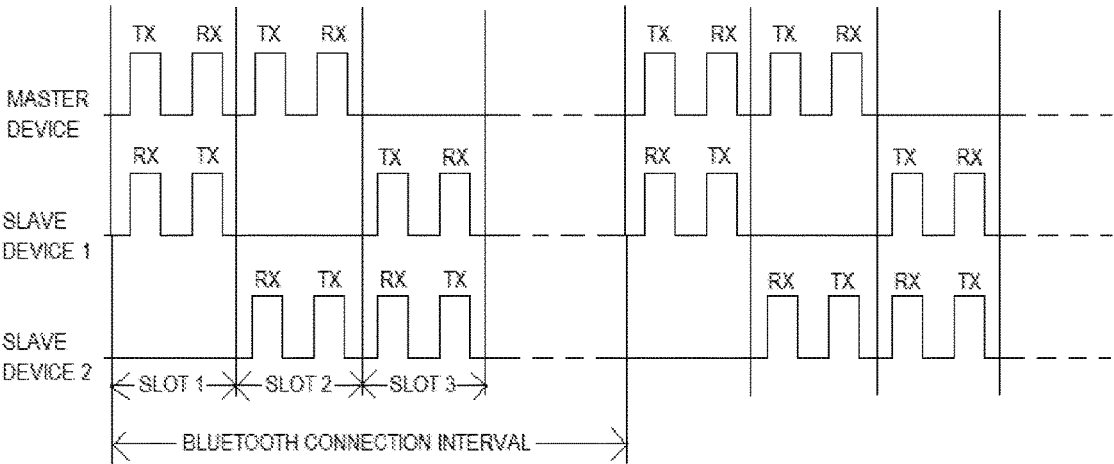


Fig. 7

1

**METHOD AND APPARATUS FOR
COMMUNICATION BETWEEN HEARING
ASSISTANCE DEVICES IN A BLUETOOTH
NETWORK**

CLAIM OF PRIORITY

This present application is a continuation of U.S. application Ser. No. 14/846,426, filed Sep. 4, 2015, which is a continuation of U.S. application Ser. No. 13/937,013, filed Jul. 8, 2013, now issued as U.S. Pat. No. 9,131,322, each of which are incorporated herein by reference in their entirety.

TECHNICAL FIELD

This application relates generally to wireless networks and, more particularly, to systems and methods for providing hearing assistance devices with wireless communication between each other while in a Bluetooth connection with a host device.

BACKGROUND

Hearing assistance devices include a variety of devices such as assistive listening devices, cochlear implants, and hearing aids. Hearing aids are useful in improving the hearing and speech comprehension of people who have hearing loss by selectively amplifying certain frequencies according to the hearing loss of the subject. A hearing aid typically includes a microphone, an amplifier and a receiver (speaker). The microphone receives sound (acoustic signal) and converts it to an electrical signal and sends it to the amplifier. The amplifier increases the power of the signal, in proportion to the hearing loss, and then sends it to the ear through the receiver. Cochlear devices may employ electrodes to transmit sound to the patient.

Wireless communication technology such as Bluetooth provides hearing assistance devices, such as hearing aids, with capability of wirelessly connecting to host devices for programming, controlling, and/or streaming audio to the hearing assistance devices. Such host devices may be implemented as dedicated host devices or implemented in general-purpose devices such as telephones, television sets, computers, and music players. To provide a listener with sound reflecting a realistic acoustic environment using multiple hearing assistance devices, such as a pair of hearing aids for the listener's left and right ears, there is a need for providing wireless communication between the host device and each of the hearing assistance devices as well as between the hearing assistance devices.

SUMMARY

A hearing assistance system provides for wireless communication between hearing assistance devices that are in a Bluetooth connection with a host device. In various embodiments, during a Bluetooth connection interval, one or more time slots are used for communication between the host device and one or more of the hearing assistance devices, while one or more additional time slots are reserved for communication between the hearing assistance devices.

In one embodiment, a hearing assistance system includes a host device, a plurality of hearing assistance devices, one or more first wireless communication links, one or more second wireless communication links, and a network control system. The host device includes a master control circuit. The plurality of hearing assistance devices includes a slave

2

control circuit in each of the hearing assistance devices. The one or more first wireless communication links are each configured to communicatively couple a hearing assistance device of the plurality of hearing assistance devices to the host device using a Bluetooth protocol. The one or more second wireless communication links are each configured to communicatively couple a hearing assistance device of the plurality of hearing assistance devices to another hearing assistance device of the plurality of hearing assistance devices. The network control system, which is implemented in the master control circuit and the slave control circuits, is configured to assign one or more first time slots for the communication over each first link of the one or more first wireless communication links within a Bluetooth connection interval and one or more second time slots for the communication over each second link of the one or more second wireless communication links within the Bluetooth connection interval. The first and second time slots are non-overlapping in time.

In one embodiment, a method for wireless communication in a hearing assistance system is provided. One or more first wireless communication links each communicatively coupling a hearing assistance device of a plurality of hearing assistance devices to a host device using a Bluetooth protocol are provided. One or more second wireless communication links each communicatively coupling a hearing assistance device of the plurality of hearing assistance devices to another hearing assistance device of the plurality of hearing assistance devices are provided. One or more first time slots for communication over each first link of the one or more first wireless communication links during a Bluetooth connection interval and one or more second time slots for communication over each second link of the one or more second wireless communication links during the Bluetooth connection interval are assigned. The first and second time slots are non-overlapping in time.

This Summary is an overview of some of the teachings of the present application and not intended to be an exclusive or exhaustive treatment of the present subject matter. Further details about the present subject matter are found in the detailed description and appended claims. The scope of the present invention is defined by the appended claims and their legal equivalents.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram illustrating an embodiment of a system including wireless communication networks providing communications for multiple devices.

FIG. 2 is a block diagram illustrating an embodiment of a master device of the system.

FIG. 3 is a block diagram illustrating an embodiment of a slave device of the system.

FIG. 4 is a block diagram illustrating an embodiment of a hearing aid system.

FIG. 5 is a block diagram illustrating an embodiment of a pair of hearing aids of the hearing aid system.

FIG. 6 is a flow chart illustrating an embodiment of a method allowing for communication between slave devices in a network.

FIG. 7 is a timing diagram illustrating an embodiment of time slots for communication during a Bluetooth connection interval.

DETAILED DESCRIPTION

The following detailed description of the present subject matter refers to subject matter in the accompanying draw-

ings which show, by way of illustration, specific aspects and embodiments in which the present subject matter may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the present subject matter. References to “an”, “one”, or “various” 5 embodiments in this disclosure are not necessarily to the same embodiment, and such references contemplate more than one embodiment. The following detailed description is demonstrative and not to be taken in a limiting sense. The scope of the present subject matter is defined by the appended claims, along with the full scope of legal equivalents to which such claims are entitled.

This document discusses a system including multiple devices communicatively coupled with each other using wireless technology. An example of the system includes a master device communicating with each device of a plurality of slave devices using a Bluetooth protocol, which does not provide for the slave devices to communicate with one another without going through the master device. However, direct communication between the slave devices may be desirable. For example, a hearing assistance system includes a host device as the master device and a plurality of hearing assistance devices, such as a pair of left and right hearing aids, each as one of the slave devices. Direct communication between the hearing assistance devices, such as direct ear-to-ear communication between the left and right hearing aids, allows for sound processing that provides the listener with realistic sound effects. The present system provides for wireless communication between the slave devices while the slave devices are in a Bluetooth connection with the master device. In various embodiments, bandwidth is reserved to allow for wireless communication between the slave devices a Bluetooth network. In various embodiments using Bluetooth technology, one or more time slots are assigned for communication between the master device and one or more of the slave devices within a Bluetooth connection interval, while one or more additional time slots within the same Bluetooth connection interval are reserved for communication between the slave devices using the Bluetooth protocol or another communication protocol. In various embodiments, the present system allows the slave devices to communicate with each other using little or no media access control (MAC) layer support while in a Bluetooth connection with the master device. In one embodiment, in which the present system includes a hearing aid system, the left and right hearing aids communicate with one another for exchanging audio information or other data while in a Bluetooth connection with a hearing aid host device, such as a smartphone.

FIG. 1 is a block diagram illustrating an embodiment of a system 100 including wireless communication networks providing communications for multiple devices. System 100 includes a master device 102 and a plurality of slave devices 104 (including 104A-N, where N can be any integer greater than 1). One example of system 100 includes a hearing assistance system, with master device 102 including a host device and the plurality of slave devices 104 including a plurality of hearing assistance devices, such as hearing aids.

System 100 includes a first network 110 and a second network 120. First network 110 includes master device 102, slave devices 104, and wireless communication links 112 (including 112A-N each coupled to the corresponding slave device 104A-N). Master device 102 includes a master control circuit 103. Slave devices 104 each include a slave control circuit, i.e., slave control circuit 105A-N each included in the corresponding device of slave device 104A-N. Wireless communication links 112 each communicatively

couple one of slave devices 104 to master device 102. For example, as illustrated in FIG. 1, link 112A communicatively couples slave devices 104A to master device 102, link 112B communicatively couples slave devices 104B to master device 102, and link 112N communicatively couples slave devices 104N to master device 102.

In one embodiment, first network 110 is a piconet providing for wireless communication via wireless communication links 112 using a Bluetooth protocol. In one embodiment, the piconet is a Bluetooth low energy (BLE) network that provides for wireless communication via wireless communication links 112 using a BLE protocol.

In various embodiments, first network 110 provides for communication between master device 102 and each of slave devices 104 via wireless communication links 112, without providing for communication directly between any two of slave devices 104. One example is piconet 110 in which the Bluetooth protocol does not provide for such direct communication between the slave devices. Thus, system 100 includes second network 120 to provide for direct communication between slave devices 104. Second network 120 includes slave devices 104 and wireless communication links 122 (including 122AB, 122AN, 122BN, etc.). Wireless communication links 122 each communicatively coupling a slave device of slave devices 104 to another slave device of slave device 104. For example, as illustrated in FIG. 1, link 122AB communicatively couples slave devices 104A to slave device 104B, link 122AN communicatively couples slave devices 104A to slave device 104N, and link 122BN communicatively couples slave devices 104B to slave device 104N.

In one embodiment, second network 120 is another piconet providing for wireless communication via wireless communication links 122 using the Bluetooth protocol. One of slave device 104 may act as the master device for piconet 120. In one embodiment, piconet 120 is a BLE network that provides for wireless communication via wireless communication links 122 using the BLE protocol. In another embodiment, second network 120 provides for wireless communication via wireless communication links 122 using a proprietary protocol. In various embodiments, second network 120 provides for wireless communication via wireless communication links 122 using, for example, code division multiple access (CDMA), time division multiple access (TDMA), frequency-division multiple access (FDMA), or orthogonal frequency-division multiplexing (OFDM) technology.

In various embodiments, first network 110 provides any one or more of wireless communication links 112, and second network 120 includes any two or more of slave devices 104 with corresponding one or more wireless communication links 122. For example, master device 102 may communicate with each of slave device 104 directly via links 112, or communicate with one of slave device 104 directly via the corresponding link and communicate with other slave devices via links 122 through that slave device (e.g., communicate with slave device 104A directly via the corresponding link 112A and communicate with slave devices 104B-N via links 122 through slave device 102A).

System 100 includes a network control system including master control circuit 103 and slave control circuits 105. The network control system controls timing and frequency of communication over each link of wireless communication links 112 and each link of wireless communication links 122. In one embodiment, the network control system assigns one or more first time slots for the communication over each link of wireless communication links 112 within a Bluetooth

connection interval and one or more second time slots for the communication over each link of the wireless communication links **122** within the Bluetooth connecting interval. The first and second time slots are non-overlapping in time. Thus, when first network **110** is a Bluetooth network, the communication over wireless communication links **122** is performed during time slots not used by the communication over wireless communication links **112** during the Bluetooth connection interval, and thus does not affect the communication in first network **110** that follows the Bluetooth protocol. In various embodiments, functions of the network control system may be distributed in master control circuit **103** and slave control circuits **105** in various manners based on design considerations.

In various embodiments, master control circuit **103** may control communication over wireless communication links **112** in a manner allowing for concurrent communication over wireless communication links **122**, and slave control circuits **105** controls communication over wireless communication links **122**. For example, master control circuit **103** may assign one or more first time slots for the communication over the each link of wireless communication links **112** during a Bluetooth connection interval while allowing for one or more second time slots for the communication over to be assigned to each link of wireless communication links **122** during the Bluetooth connecting interval. The first and second time slots are non-overlapping in time. In one example, master control circuit **103** further assigns the one or more second time slots. In another example, at least one of slave control circuit **105** assigns the one or more second time slots.

In various embodiments, the network control system also controls the frequency of communication in networks **110** and **120**. Master control circuit **103** allocates a channel map and a hop sequence in addition to assigning the time slots to each of slave devices **104**. In various embodiments, the channel maps for slave devices **104** are either the same for each slave device or known to each slave device, and the hop sequence is either synchronized or known by each slave device in communication with the master device. Slave devices **104** are configured to communicate with each other or with other peripheral devices. In various embodiments, when the time slots for communication to and from slave devices **104** are allocated as consecutive time slots in the Bluetooth connection, or are known for each slave device, the available (remaining, unused) time slots are used for proprietary communication outside of the Bluetooth connection. In order to utilize the physical layer state machines, the packets will have a structure similar to that of the Bluetooth connection.

The BLE protocol allows a master device to maintain connections with up to seven slave devices. Thus, when first network **110** provides for communication using the BLE technology, it can include master device **102** communicating with up to seven slave devices **104**. In practice, the number of slave device may be lower than seven. When system **100** is a hearing assistance system including a hearing aid host device and a pair of left and right hearing aids, only two wireless links, one between the host device and the left hearing aid and the other between the host device and the right hearing aid, need to be maintained in first network **110**. The host device acts as master device **102** and the left and right hearing aids act as slave devices **104**. In various embodiments, master device **102** is configured to be the network controller using its link layer media access protocol to assign time slots and frequencies to slave devices **104**. The Bluetooth protocol uses adaptive frequency hopping

(AFH) to help mitigate interference and for system **100** to be regulatory compliant. In addition, other devices in the piconet **110** may be assigned time slots to receive and transmit information to and from master device **102**. This multiple access scheme is known as time division multiple access (TDMA). The Bluetooth connection interval is used to allow slave devices **104** to be awake at certain intervals to receive information from, or send information to, the host device. It also facilitates a much lower duty cycle since slave devices **104** can go to sleep between connection intervals.

In various embodiments, the circuit of each element of system **100** including its various embodiments discussed in this document, for example master control circuit **103** and slave control circuits **105** and their various embodiments as discussed in this document, may be implemented using hardware, software, firmware or a combination of hardware, software and/or firmware. In various embodiments, the network control system including master control circuit **103** and slave control circuits **105** may be implemented using one or more circuits specifically constructed to perform one or more functions discussed in this document or one or more general-purpose circuits programmed to perform such one or more functions. Examples of such general-purpose circuit can include a microprocessor or a portion thereof, a microcontroller or portions thereof, and a programmable logic circuit or a portion thereof.

FIG. 2 is a block diagram illustrating an embodiment of a master device **202**, which represent an embodiment of master device **102**. Master device **202** includes a master communication circuit **205**, which provides master device **202** with wireless communication capabilities. Master communication circuit **205** includes a master control circuit **203** and a master telemetry circuit **206**. Master telemetry circuit **206** transmits and receives signals using a link of wireless communication links **112**. Master control circuit **203** controls the transmission and receiving of the signals and represents an embodiment of master control circuit **103**.

FIG. 3 is a block diagram illustrating an embodiment of a slave device **304**, which represent an embodiment of one of slave devices **104**. Slave device **304** includes a slave communication circuit **307**, which provides slave device **304** with wireless communication capabilities. Slave communication circuit **307** includes a slave control circuit **305** and a slave telemetry circuit **308**. Slave telemetry circuit **308** transmits and receives signals using a link of wireless communication links **112** and one or more links of wireless communication links **122**. Slave control circuit **305** controls the transmission and receiving of the signals and represents an embodiment of slave control circuit **105**.

In one embodiment, master control circuit **203** assigns one or more time slots for the communication over each link of wireless communication links **112** and **122** according to a timing sequence. In one embodiment, master control circuit **203** also allocates one or more frequency channels for the communication over each link of wireless communication links **112** and **122** according to a frequency channel map and a frequency hop sequence. Slave control circuit **205** controls communication over each link of wireless communication link(s) **122** using the one or more time slots and frequency channel assigned by master control circuit **203**.

In another embodiment, master control circuit **203** assigns one or more first time slots for the communication over each link of wireless communication link **112** according to a first timing sequence. In one embodiment, master control circuit **203** also allocate a first frequency channel for the communication over each link of wireless communication link **112** according to a first frequency channel map and a first

frequency hop sequence. Slave control circuit 205 assigns one or more second time slots for the communication over each link of wireless communication link 122 based on the one or more first time slots (i.e., occupied time slot(s)) and a second timing sequence. In one embodiment, slave control circuit 205 also allocates a second frequency channel for the communication over each link of wireless communication link 122 based on a second frequency channel map and a second frequency hop sequence.

FIG. 4 is a block diagram illustrating an embodiment of a hearing aid system 400, which represents an embodiment of system 100. System 400 includes a first network 410 and a second network 420. First network 410 includes a hearing aid host device 402, a pair of a left hearing aid 404L and a right hearing aid 404R, and wireless communication links 412L and 412R. Hearing aid host device 402 functions as a master device in first network 410 and may include master device 202. Left and right hearing aids 404L-R each function as a slave device in first network 410 and may include slave device 304. Examples of host device 402 include a smartphone, a computer, an audio streaming device, and a dedicated hearing aid host device. Wireless communication link 412L communicatively couples left hearing aid 404L to host device 402. Wireless communication link 412R communicatively couples right hearing aid 404R to host device 402. In one embodiment, first network 410 is a piconet providing for wireless communication via wireless communication links 412L-R using a Bluetooth protocol. In one embodiment, the piconet is a BLE network that provides for wireless communication via wireless communication links 412L-R using a BLE protocol.

In various embodiments, first network 410 provides for communication between host device 402 and each of left and right hearing aids 404L-R via wireless communication link 412L-R, without providing for communication directly between left and right hearing aids 404L-R. One example is the piconet in which the Bluetooth protocol does not provide for such direct communication between left and right hearing aids 404L-R. Thus, system 400 includes second network 420 to provide for direct communication between left and right hearing aids 404L-R. Second network 420 includes left and right hearing aids 404L-R and a wireless communication link 422L-R. Wireless communication link 422L-R communicatively couples left and right hearing aids 404L-R to each other.

In one embodiment, second network 420 is another piconet providing for wireless communication via wireless communication link 422L-R using the Bluetooth protocol. One of hearing aids 404L-R may act as the master device for second network 420. In one embodiment, piconet 420 is a BLE network that provides for wireless communication via wireless communication link 422L-R using the BLE protocol. In another embodiment, second network 420 provides for wireless communication via wireless communication link 422L-R using a proprietary protocol. In various embodiments, second network 420 provides for wireless communication via wireless communication link 422L-R using, for example, CDMA, TDMA, FDMA, or OFDM technology.

In one embodiment, host device 402 assigns both hearing aids 404L-R consecutive time slots and uses the same frequency for each of hearing aids 404L-R in any given connection interval. Hearing aids 404L-R hop to the same frequencies at around the same time frame. In an idle connection (e.g., a connection for low data rate information or maintaining synchronization), there may be a significant amount of “dead time” during which bandwidth is not used for the Bluetooth communication over wireless communi-

cation links 412L-R. Within this “dead time” it may be possible for other communication, such as the communication over wireless communication link 422L-R, to take place. In this case hearing aids 404L-R may communicate with each other, such as in an ear to ear communication through which hearing aids 404L-R can exchange audio or other data. If each of hearing aids 404L-R knows that they are already on the same frequency and the relative time of their sleep wake cycles, they can use the bandwidth not used by the Bluetooth communication to communicate. In this case one of hearing aids 404L-R may act as master and can use a communication similar to that which is used in Bluetooth or BLE communication to better utilize the protocol engines on the Bluetooth ASICs (application-specific integrated circuits). It is also possible to use a proprietary protocol to communicate between hearing aids 404L-R. Only a minor modification to the Bluetooth host device is needed to facilitate this communication between hearing aids 404L-R and/or other networked devices.

In one embodiment, frequency hopping is synchronized between hearing aids 404L-R. Hearing aids 404L-R are each given the same frequency map, the same starting frequency, and the same hop interval. In one embodiment (e.g., a classic Bluetooth protocol), hearing aids 404L-R are each given the same hop instructions. The time slots for hearing aids 404L-R are consecutive, with a slot used by left hearing aid 404L and the immediately adjacent slot used by right hearing aid 404R. An example of such time slots is illustrated in FIG. 7.

In another embodiment, hearing aids 404L-R are independently controlled. Hearing aids 404L-R are each provided with knowledge of the frequency map, hop sequence, and time slot of the other device(s) in first network 410 and second network 420 in order to facilitate communication. This approach requires greater current consumption because the devices must hop to meet each other, communicate, and hop back to where the host device is by the next connection interval.

Other embodiments are also available using various proprietary multiple access techniques and modulation schemes. In various embodiments, a simpler approach uses the same packet time slots and the same packet sizes allowed for the packets in a “normal communication mode”, while more complicated approach may allow more time slots to be allocated for standard and/or non-standard communication protocols without deviating from the present subject matter.

FIG. 5 is a block diagram illustrating an embodiment of hearing aid set 504 including a pair of a left hearing aid 504L and a right hearing aid 504R. Left hearing aid 504L represents an embodiment of left hearing aid 404L and includes a microphone 524L, a wireless communication circuit 507L, a processing circuit 525L, and a receiver 526L. Microphone 524L receives sounds from the environment of the hearing aid wearer. Wireless communication circuit 507L represents an embodiment of slave communication circuit 307 and wirelessly communicates with host device 402 and/or right hearing aid 504R, including receiving an audio signal from host device 402 directly or through right hearing aid 504R. Processing circuit 525L processes the sounds received by microphone 524L and/or the audio signal received by wireless communication circuit 507L to produce a left output sound. Receiver 526L transmits the left output sound to the left ear canal of the hearing aid wearer.

Right hearing aid 504R represents an embodiment of right hearing aid 404R and includes a microphone 524R, a wireless communication circuit 507R, a processing circuit 525R, and a receiver 526R. Microphone 524R receives

sounds from the environment of the hearing aid wearer. Wireless communication circuit 507R represents an embodiment of slave communication circuit 307 and wirelessly communicates with host device 402 and/or left hearing aid 504L, including receiving an audio signal from host device 402 directly or through left hearing aid 504L. Processing circuit 525R processes the sounds received by microphone 524R and/or the audio signal received by wireless communication circuit 507R to produce a right output sound. Receiver 526R transmits the right output sound to the right ear canal of the hearing aid wearer.

FIG. 6 is a flow chart illustrating an embodiment of a method 600 that allows for communication between slave devices in a network. In one embodiment, method 600 is performed by system 100, including its various embodiments discussed in this document. The network control system, including various embodiments of master control circuit 103 and slave control circuits 105, is configured to perform method 600.

At 602, one or more first wireless communication links each communicatively coupling a slave device of a plurality of slave devices to a master device are provided. In one embodiment, the plurality of slave devices includes a plurality of hearing assistance devices, and the master device includes a host device for the plurality of hearing assistance devices. In one embodiment, the one or more first wireless communication links each communicatively couple a hearing assistance device of the plurality of hearing assistance devices to the host device using a Bluetooth protocol. In one embodiment, the Bluetooth protocol is a BLE protocol. In one embodiment, the plurality of hearing assistance devices includes a pair of hearing aids for delivering sounds to a hearing aid wearer's left and right ears, and the host device is a hearing aid host device. In various embodiments, the hearing aid host device may be implemented as a dedicated device or in a smartphone, a computer, a music player, or an audio streaming device.

At 604, one or more second wireless communication links each communicatively coupling a slave device of the plurality of hearing assistance devices to another slave device of the plurality of slave devices are provided. In one embodiment, the one or more second wireless communication links each communicatively couple a hearing assistance device of the plurality of hearing assistance devices to another hearing assistance device of the plurality of hearing assistance devices. In one embodiment, the one or more first wireless communication links and the one or more second wireless communication links are both provided using the Bluetooth protocol, such as the BLE protocol. In another embodiment, the one or more first wireless communication links are provided using the Bluetooth protocol, and the one or more second wireless communication links are provided using a proprietary protocol.

At 606, one or more first time slots for communication over each first link of the one or more first wireless communication links and one or more second time slots for communication over each second link of the one or more second wireless communication links are assigned. The first and second time slots are non-overlapping in time. In one embodiment, the one or more first time slots and the one or more second time slots are assigned within a Bluetooth connection interval. In one embodiment, the one or more first time slots and the one or more second time slots are assigned by the master device according to a timing sequence. One or more frequency channels for the communication over the each of the one or more first wireless communication links and each of the second wireless com-

munication links are also allocated by the master device according to a frequency channel map and a frequency hop sequence. In another embodiment, the one or more first time slots are assigned by the master device according to a first timing sequence, and the one or more second time slots are assigned by a slave device of the plurality of slave devices according to a second timing sequence. One or more first frequency channels for the communication over the one or more first wireless communication links are allocated by the master device according to a first frequency channel map and a first frequency hop sequence. One or more second frequency channels for the communication over the one or more second wireless communication links are assigned by a slave device of the plurality of slave devices based on a second frequency channel map and a second frequency hop sequence.

FIG. 7 is a timing diagram illustrating an embodiment of time slots for communication during a Bluetooth connection interval. For the purpose of illustration rather than restriction, the timing diagram is for communications in a network including a master device and two slave devices. In various embodiments, the illustrated time slot assignment may be applied to a network with two or more slave devices, with the limit set by the duration of the Bluetooth connection interval.

In the illustrated embodiment, a first time slot (SLOT 1) allows for communication between the master device and slave device 1, including data transmission (TX) by the master device and receiving (RX) by slave device 1 and data transmission (TX) by slave device 1 and receiving (RX) by the master device. A second time slot (SLOT 2) allows for communication between the master device and slave device 2, including data transmission (TX) by the master device and receiving (RX) by slave device 2 and data transmission (TX) by slave device 2 and receiving (RX) by the master device. A third time slot (SLOT 3) allows for communication between slave device 1 and slave device 2, including data transmission (TX) by slave device 1 and receiving (RX) by slave device 2 and data transmission (TX) by slave device 2 and receiving (RX) by slave device 1. When applied to system 100, for example, the first and second time slots allow for communication over wireless communication links 112, and the third time slot allow for communication over one of wireless communication links 122. When applied to system 400, for example, the first and second time slots allow for communication between hearing aid host device 402 and each of left hearing aid 404L and right hearing aid 404R, and the third time slot allow for communication between left hearing aid 404L and right hearing aid 404R.

The present subject matter is demonstrated for hearing assistance devices, including hearing aids, including but not limited to, behind-the-ear (BTE), in-the-ear (ITE), in-the-canal (ITC), receiver-in-canal (RIC), or completely-in-the-canal (CIC) type hearing aids. It is understood that behind-the-ear type hearing aids may include devices that reside substantially behind the ear or over the ear. Such devices may include hearing aids with receivers associated with the electronics portion of the behind-the-ear device, or hearing aids of the type having receivers in the ear canal of the user, including but not limited to receiver-in-canal (RIC) or receiver-in-the-ear (RITE) designs. The present subject matter can also be used in hearing assistance devices generally, such as cochlear implant type hearing devices. It is understood that other hearing assistance devices not expressly stated herein may be used in conjunction with the present subject matter.

11

The methods illustrated in this disclosure are not intended to be exclusive of other methods within the scope of the present subject matter. Those of ordinary skill in the art will understand, upon reading and comprehending this disclosure, other methods within the scope of the present subject matter. The above-identified embodiments, and portions of the illustrated embodiments, are not necessarily mutually exclusive. These embodiments, or portions thereof, can be combined. In various embodiments, the methods are implemented using a data signal embodied in a carrier wave or propagated signal, that represents a sequence of instructions which, when executed by one or more processors cause the processor(s) to perform the respective method. In various embodiments, the methods are implemented as a set of instructions contained on a computer-accessible medium capable of directing a processor to perform the respective method. In various embodiments, the medium is a magnetic medium, an electronic medium, or an optical medium.

The above detailed description is intended to be illustrative, and not restrictive. Other embodiments will be apparent to those of skill in the art upon reading and understanding the above description. The scope of the invention should, therefore, be determined with reference to the appended claims, along with the full scope of equivalents to which such claims are entitled.

What is claimed is:

1. A system including a master device and a plurality of slave devices, the system comprising:

a first hearing assistance device configured to be a first slave device of the plurality of slave devices, to perform wireless communication with the master device using a Bluetooth protocol during one or more first time slots in a Bluetooth connection interval, and to perform wireless communication with a second slave device of the plurality of slave devices during one or more second time slots of the Bluetooth connection interval, the one or more second time slots non-overlapping with the one or more first time slots.

2. The system of claim 1, wherein the first hearing assistance device comprises a control circuit configured to receive from the master device assignment of the one or more second time slots and to control the wireless communication with the second slave device using the one or more second time slots assigned by the master device.

3. The system of claim 2, wherein the control circuit is further configured to receive from the master device allocation of one or more frequency channels for the wireless communication with the second slave device and to control the wireless communication with the second slave device using the one or more frequency channels allocated by the master device.

4. The system of claim 1, wherein the first hearing assistance device comprises a control circuit configured to assign the one or more second time slots and to control the wireless communication with the second slave device using the assigned one or more second time slots.

5. The system of claim 4, wherein the slave control circuit is further configured to allocate one or more frequency channels for the wireless communication with the second slave device and to control the wireless communication with the second slave device using the allocated one or more frequency channels.

6. The system of claim 1, wherein the first hearing assistance device comprises a hearing aid.

7. A system including a master device and a plurality of slave devices each configured to communicate with the

12

master device using a Bluetooth protocol during one or more first time slots in a Bluetooth connection interval, the system comprising:

a first hearing assistance device configured to be a first slave device of the plurality of slave devices and to perform wireless communication with a second slave device of the plurality of slave devices during one or more second time slots of the Bluetooth connection interval the one or more second time slots non-overlapping with the one or more first time slots,

wherein the first hearing assistance device is configured to perform the wireless communication with the second slave device using the Bluetooth protocol or a proprietary protocol.

8. The system of claim 7, wherein the first hearing assistance device is configured to perform the wireless communication with the second slave device using a proprietary protocol.

9. The system of claim 1, further comprising a second hearing assistance device configured to be the second slave device.

10. The system of claim 9, wherein the first hearing assistance device and the second hearing assistance device are configured to perform wireless ear-to-ear communication with each other during the one or more second time slots.

11. The system of claim 10, wherein the first hearing assistance device and the second hearing assistance device comprise a control circuit configured to assign the one or more second time slots based on the one or more first time slots and a predetermined timing sequence.

12. The system of claim 11, wherein the first hearing assistance device and the second hearing assistance device comprise a pair of left and right hearing aids.

13. A method for wireless communication in a hearing assistance system including a master device and a plurality of slave devices each configured to communicate with the master device via a Bluetooth wireless communication link, the method comprising:

configuring a first hearing assistance device to function as a first slave device of the plurality of slave devices; performing wireless communication between the first hearing assistance device and the master device using a Bluetooth protocol during one or more first time slots in a Bluetooth connection interval; and

performing wireless communication between the first hearing assistance device and a second slave device of the plurality of slave devices during one or more second time slots of the Bluetooth connection interval, the one or more second time slots non-overlapping with the one or more first time slots.

14. The method of claim 13, further comprising configuring a second hearing assistance device to function as the second slave device of the plurality of slave devices, and wherein performing the wireless communication between the first hearing assistance device and the second slave device comprises performing ear-to-ear communication between the first and second hearing assistance devices.

15. The method of claim 14, wherein performing the ear-to-ear communication between the first and second hearing assistance devices comprises performing the ear-to-ear communication between a left hearing aid and a right hearing aid.

16. The method of claim 13, wherein configuring the first hearing assistance device comprises a hearing aid.

17. The method of claim 13, wherein performing the wireless communication between the first hearing assistance device and the second slave device comprises:

receiving from the master device assignment of the one or more second time slots; and
performing the wireless communication with the second slave device using the received assignment of the one or more second time slots.

18. The method of claim 17, wherein performing the wireless communication between the first hearing assistance device and the second slave device further comprises:

receiving from the master device allocation of one or more frequency channels; and
performing the wireless communication with the second slave device using the received allocation of the one or more frequency channels.

19. The method of claim 13, wherein performing the wireless communication between the first hearing assistance device and the second slave device comprises:

assigning the one or more second time slots using the first hearing assistance device; and
performing the wireless communication with the second slave device using the assigned one or more second time slots.

20. The method of claim 19, wherein performing the wireless communication between the hearing assistance device and the second slave device further comprises:

allocate one or more frequency channels using the first hearing assistance device; and
performing the wireless communication with the second slave device using the allocated one or more frequency channels.

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