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(71) Applicant: **HEWLETT PACKARD ENTERPRISE DEVELOPMENT LP** [US/US]; 11445 Compaq Center Drive West, Houston, Texas 77070 (US).

(72) Inventors: **PEFKIANAKIS, Ioannis**; 1501 Page Mill Road, Palo Alto, California 94304-1100 (US). **ALI, Kamran Ali**; 1501 Page Mill Road, Palo Alto, California 94304-1100 (US).

(74) Agents: **ALLEN, Matthew R.** et al.; Hewlett Packard Enterprise, 3404 E. Harmony Road, Mail Stop #79, Fort Collins, Colorado 80528 (US).

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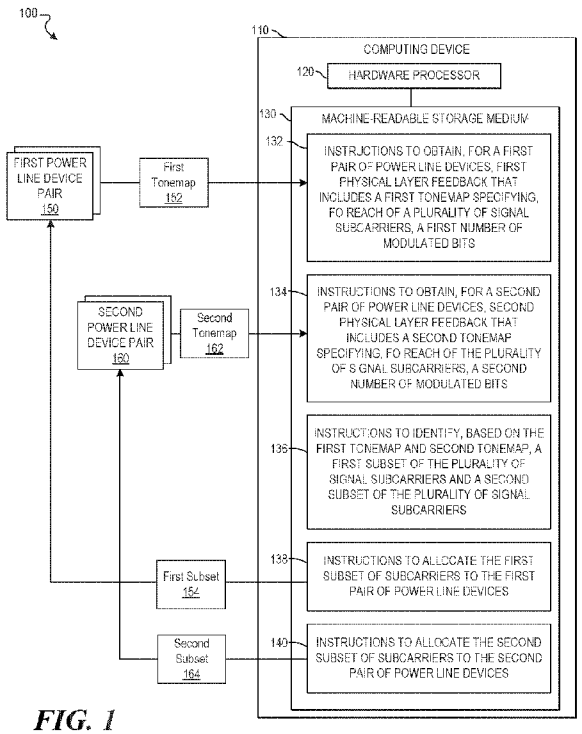

FIG. 1

(57) Abstract: Examples relate to allocating subcarriers in power line networks. In one example, a computing device may: obtain, for each of a plurality of power line device pairs, physical layer feedback that includes a tonemap specifying, for each of a plurality of signal subcarriers, a number of modulated bits; identify, for each of the plurality of power line device pairs and based on the tonemaps, a subset of the plurality of signal subcarriers; and allocate, to each of the plurality of power line device pairs, a corresponding one of the identified subsets of the plurality of signal subcarriers.

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ALLOCATING SUBCARRIERS IN POWER LINE NETWORKS

BACKGROUND

[0001] Power Line Communication (PLC) technology is form of communications that uses electrical wiring to carry both data and Alternating Current (AC) to various devices. PLC devices, e.g., adapters that plug into a home or office power outlet, may be used to form PLC networks, which can be used to transmit data between devices connected to the PLC devices. For example, a PLC device may be used to extend data communications from one portion of a building to another, using existing power lines as opposed to Wi-Fi range extenders, coaxial cables, twisted pair cabling, and other alternatives. PLC technology may offer some entities an additional form of network communications that may be preferable to the alternatives.

BRIEF DESCRIPTION OF THE DRAWINGS

[0002] The following detailed description references the drawings, wherein:

[0003] FIG. 1 is a block diagram of an example computing device for allocating subcarriers in a power line network.

[0004] FIG. 2A depicts an illustration of a first example tonemap used to allocate subcarriers in power line networks.

[0005] FIG. 2B depicts an illustration of a second example tonemap used to allocate subcarriers in power line networks.

[0006] FIG. 3 is a data flow depicting the allocation of subcarriers in a power line network.

[0007] FIG. 4 is a flowchart of an example method for allocating subcarriers in power line networks.

[0008] FIG. 5 is a flowchart of an example method for allocating subcarriers in a power line network.

Detailed Description

[0009] Power Line Communications (PLC) devices may be used to create data networks, e.g., using CSMA/CA MAC-layer protocols to access the power line communication medium, which is based on an orthogonal frequency division multiplexing (OFDM) scheme using 917 signal subcarriers. PLC networks are capable of performing at relatively high data transfer speeds; however, frequency channelization and spectrum sharing are not supported. To avoid negative impacts on performance, e.g., in PLC networks with two or more pairs of PLC devices, subcarriers may be allocated to PLC device pairs in a manner designed to achieve relatively high PLC network throughput and allow all PLC devices operating on the PLC network to communicate at the same time.

[0010] By way of example, two pairs of PLC devices may be part of a PLC network for transmitting data. Each pair of PLC devices may produce a tonemap that indicates signal strength across each signal subcarrier. The tonemap may indicate strength, for example, by specifying the number of modulated bits for each signal subcarrier of the PLC network at a given point in time, or over a period of time. For example, a relatively high number of modulated bits would indicate a relatively high quality signal for a particular signal subcarrier, while a relatively low number of modulated bits would indicate a relatively low quality signal for another signal subcarrier. The tonemaps may be used to allocate subcarriers to each pair of PLC devices.

[0011] For example, tonemaps may reveal that a first pair of devices has high performance/modulation with a first subset of the signal subcarriers but poor performance/modulation with a second subset of the signal subcarriers, and a second pair of devices has high performance/modulation with the second subset but poor performance/modulation with the first subset. In this situation, the first subset may be allocated to the first pair of devices while the second subset is allocated to the second pair of devices. This allows both pairs of devices to communicate at the same time and at a relatively high level of performance. Further details regarding the allocation of signal subcarriers is described below.

[0012] Referring now to the drawings, FIG. 1 is a block diagram 100 of an example computing device 110 for allocating subcarriers in power line networks. Computing device 110 may be, for example, a power line adapter or other power line device, or a computing device connected to the power line network, such as a personal computer, a server computer, or any other similar electronic device capable of communicating with PLC network devices. In the example implementation of FIG. 1, the computing device 110 includes a hardware processor, 120, and machine-readable storage medium, 130.

[0013] Hardware processor 120 may be one or more central processing units (CPUs), semiconductor-based microprocessors, and/or other hardware devices suitable for retrieval and execution of instructions stored in machine-readable storage medium, 130. Hardware processor 120 may fetch, decode, and execute instructions, such as 132-140, to control processes for allocating subcarriers in power line networks. As an alternative or in addition to retrieving and executing instructions, hardware processor 120 may include one or more electronic circuits that include electronic components for performing the functionality of one or more instructions.

[0014] A machine-readable storage medium, such as 130, may be any electronic, magnetic, optical, or other physical storage device that contains or stores executable instructions. Thus, machine-readable storage medium 130 may be, for example, Random Access Memory (RAM), an Electrically Erasable Programmable Read-Only Memory (EEPROM), a storage device, an optical disc, and the like. In some implementations, storage medium 130 may be a non-transitory storage medium, where the term "non-transitory" does not encompass transitory propagating signals. As described in detail below, machine-readable storage medium 130 may be encoded with executable instructions: 132-140, for allocating subcarriers in power line networks.

[0015] FIG. 1 also depicts two separate pairs of power line devices, the first power line device pair 150 and the second power line device pair 160. Each device included in a pair may be, for example, a power line adapter that plugs into an electrical outlet. While the power line device pairs are depicted separately from

the computing device 110, in some implementations the computing device 110 may be or may be included in one of the power line devices of the device pairs, e.g., such that a power line adapter paired with another power line adapter executes instructions 132-140.

[0016] As shown in FIG. 1, the hardware processor 120 executes instructions 132 to obtain, from the first power line device pair 150, physical layer feedback in the form of a first tonemap 152 that specifies a number of modulated bits per subcarrier, e.g., for communications between the PLC devices included in the first pair 150. The first tonemap 152 may, in some implementations, be one of many provided to the computing device 110 periodically, randomly, or at specific points in time, e.g., in response to user input and/or upon detecting data transmissions between the devices of the first pair 150.

[0017] The hardware processor 120 executes instructions 134 to obtain, for a second power line device pair 160, physical layer feedback in the form of a second tonemap 162 that specifies a number of modulated bits per subcarrier, e.g., for communications between the PLC devices included in the second pair 160. As with the first tonemap 152, the second tonemap 162 may, in some implementations, be one of many provided to the computing device 110 periodically, randomly, or at specific points in time.

[0018] While two pairs of power line devices are depicted in the example of FIG. 1, in some implementations additional pairs of power line devices may also provide corresponding tonemaps to the computing device 110. Each pair of power line devices that provides a tonemap to the computing device operates on the same PLC network as each other pair providing tonemaps. For example, each pair of power line devices may be placed in electrical outlets throughout a home or place of business and connected to the same circuit.

[0019] The hardware processor 120 executes instructions 136 to identify, based on the first tonemap 152 and second tonemap 162, a first and second subset of the signal subcarriers. The manner in which the first and second subsets are identified may vary depending on the implementation and a variety of other factors. In some implementations, the computing device 110 identifies the

subsets in a manner designed to maximize modulation across the PLC network. This may be performed, for example, by assigning each subcarrier to a subset for the pair of power line devices for which the subcarrier experienced the highest modulation/performance. E.g., if subcarriers 1-100 experienced 10 modulated bits for the first power line device pair 150 and 4 modulated bits for the second power line device pair 160, subcarriers 1-100 may be identified as belonging to a first subset for the first power line device pair 150.

[0020] In some implementations, the computing device 110 identifies the subsets based on bandwidth values obtained from each pair of power line devices. For example, each pair of power line devices may have certain bandwidth requirements or expectations based on previous use. In this situation, the computing device 110 may identify subcarriers in a manner designed to meet the bandwidth requirements, instead of or in addition to maximizing total PLC network throughput. In some implementations, the computing device 110 may generate estimated bandwidth values for each pair of PLC devices using the modulated bits identified in the corresponding tonemaps, and the estimated bandwidth values may be used to identify subcarrier subsets. In some implementations, power consumption may be taken into consideration when identifying subsets of subcarriers. For example, subcarriers may be identified in a manner designed to meet certain minimum bandwidth requirements while also minimizing power consumption. In some implementations, subcarriers identified as belonging to one subset are not included in any other subset, e.g., each subset includes subcarriers that are different from those included in each other subset.

[0021] In some implementations, one or more known selection algorithms may be used to identify subcarrier subsets. For example, subsets may be identified using recursive combinations designed to meet certain PLC device pair throughput estimates, power consumption levels, bandwidth requirements, and/or other goals described above. Other algorithms, such as exhaustive searching and greedy approaches may also be used.

[0022] The hardware processor 120 executes instructions 138 to allocate the first subset 154 of subcarriers to the first pair of power line devices 150. The first

subset 154 may, in some implementations, include instructions that cause the first power line device pair 150 to communicate with each other using only the subcarriers specified in the first subset 154.

[0023] The hardware processor 120 executes instructions 140 to allocate the second subset 164 of subcarriers to the second pair of power line devices 160. As with the first subset 154, the second subset 164 may include instructions that cause the second power line device pair 160 to communicate with each other using only the subcarriers specified in the second subset 164.

[0024] FIG. 2A depicts an illustration of a first example tonemap 200 used to allocate subcarriers in power line networks, such as an allocation of the first subset 154 to the first pair of power line devices 150 described above with respect to FIG. 1. FIG. 2B depicts an illustration of a second example tonemap 250 used to allocate subcarriers in power line networks, such as an allocation of the second subset 164 to the second pair of power line devices 160 described above with respect to FIG. 1.

[0025] For example, in FIG. 2A, the tonemap indicates, for subcarriers 1-917, the number of modulated bits per subcarrier. A subset of the subcarriers, identified in the tonemap 200 as the subcarriers between dotted lines 202 and 204, perform – on average – worse than other subcarriers. When looking at the example tonemap 250 of FIG. 2B, on the other hand, those same subcarriers between dotted lines 252 and 254, perform – on average – relatively well compared to the performance measured in the first tonemap 200. Using these example tonemaps, 200 and 250, a first subset of subcarriers, e.g., subcarriers 1-175 and 500-917, may be allocated to the pair of PLC devices associated with the first tonemap 200. A second subset of subcarriers, e.g., 176-499, may be allocated to the pair of PLC devices associated with the second tonemap 250.

[0026] The example tonemaps, subsets, and allocation described above is one example that uses a relatively coarse identification and allocation of subcarriers based on performance, e.g., modulation. As noted above, the manner in which subcarriers are allocated may vary based on a variety of factors. In some implementations, each individual subcarrier may be assigned based on one or

more of the factors described above. For example, a PLC device may assign each individual subcarrier based on which pair of PLC devices the subcarrier performed better on, with ties being broken by which pair of devices has a higher bandwidth requirement or higher average throughput. In some implementations, subcarrier may be allocated to a pair of PLC devices even when that subcarrier has higher modulation with a different pair of PLC devices, e.g., based on minimum bandwidth requirements or power consumption factors. Other methods of allocation may also be used.

[0027] FIG. 3 is a data flow 300 depicting the allocation of subcarriers in a power line network. Each pair of power line devices, 310, 320, 330, may be the same as or similar to the pairs of power line devices described above with respect to FIG. 1. In addition to the power line device pairs, the data flow 300 includes a subcarrier allocation device 340, which may be any computing device, such as computing device 110 of FIG. 1. While the subcarrier allocation device 340 is depicted in the data flow 300 as a device that is separate from the PLC device pairs, 310, 320, 330, in some implementations the subcarrier allocation device 340 may be implemented within or by one of the PLC devices included in one of the PLC device pairs, e.g., implemented in a power line adapter.

[0028] The subcarrier allocation device 340 receives physical layer feedback, e.g., in the form of tonemaps 312, 322, 332, from each pair of power line devices, e.g., power line device pair 1 310, device pair 2 320, and device pair N 330. As indicated in the data flow, any number of PLC device pairs may be included in a PLC network and provide tonemaps to the subcarrier allocation device 240. Each tonemap specifies, for each signal subcarrier, a number of modulated bits. Tonemaps may be expressed in a variety of ways and, in some implementations, the tonemaps may be expressed as depicted in FIGs. 2A and 2B. In the example data flow 300, example tonemap 312 is depicted in a table format, specifying the number of modulated bits for each subcarrier within a table.

[0029] In some implementations, power line device pairs, e.g., 310, 320, 330, may provide additional information to the subcarrier allocation device, such as bandwidth requirements, throughput measurements, or other information that may

be used to allocate subcarriers. In some implementations, a third party, such as a user or a separate computing device, may provide some or all of this additional information to the subcarrier allocation device 340.

[0030] The subcarrier allocation device 340 identifies, based on the tonemaps, a subset of signal subcarriers for each pair of power line devices. For example, the data flow depicts subsets 1 314, 2 324, and N 334, which were identified using the tonemaps 1 312, 2, 322, and N 332, respectively. The subset 334 for device pair N 330 includes, by way of example, subcarriers 100-150, 375-475, and 800-900. The manner in which the subcarrier allocation device 340 identifies subsets, e.g., the information and method used, may vary. In implementations where additional information, such as bandwidth, throughput, or power consumption, is available to the subset allocation device 340, the additional information may be used in identifying subcarrier subsets.

[0031] In the example data flow 300, the subcarrier allocation device 340 allocates one of the identified subcarrier subsets to each power line device pair. For example, allocation 1 316 corresponds to subset 1 314 and is provided to the power line device pair 1 310, allocation 2 326 corresponds to subset 2 324 and is provided to power line device pair 2 320, and allocation N 336 corresponds to subset N 334 and is provided to power line device pair N 330. The allocation of subcarriers to pairs of power line devices causes the corresponding pairs of devices to communicate to each other using only the allocated subcarriers. For example, allocation N 336 specifies that the power line devices included in power line device pair N 330 should only communicate with each other using subcarriers 100-150, 375-475, and 800-900.

[0032] The example data flow 300 depicts a process that may vary and may be repeated over time, e.g., making adjustments to allocations based on changing conditions. For example, electrical interference may cause changes in tonemaps, which may cause the subcarrier allocation device 340 to make new allocations. In situations where new PLC device pairs are added to the PLC network, or existing PLC device pairs are removed from the PLC network, subcarriers may be reallocated. In some implementations, subcarriers may be reallocated on a

regular basis, e.g., hourly, daily, or weekly, and/or may occur in response to a particular event, e.g., a new source of electrical interference being added to the network or in response to changes in bandwidth requirements or average throughput experienced by one or more of the PLC device pairs. Reallocation, when performed, may be performed in the same or a similar manner as the method for allocation described above.

[0033] FIG. 4 is a flowchart of an example method 400 for allocating subcarriers in power line networks. The method 400 may be performed by a computing device, such as a computing device described in FIG. 1, e.g., in the form of a power line adapter or personal computer. Other computing devices may also be used to execute method 400. Method 400 may be implemented in the form of executable instructions stored on a machine-readable storage medium, such as the storage medium 130, and/or in the form of electronic circuitry, such as an FPGA or ASIC.

[0034] For each of a plurality of power line device pairs, physical layer feedback is obtained, the physical layer feedback includes a tonemap specifying, for each of a plurality of signal subcarriers, a number of modulated bits (402). The number of modulated bits may provide an indication, for each subcarrier, of the performance of that subcarrier with respect to communications between the corresponding pair of power line devices, e.g., with a higher number of modulated bits indicating higher performance, than a lower number of modulated bits. The power line device pairs that provide tonemaps may all be included in a single PLC network, e.g., they are all attached to the same electric circuit, such as a home power circuit or the power circuit of an office building.

[0035] For each of the power line device pairs, a subset of the signal subcarriers is identified based on the tonemaps (404). Based on one or more factors, which may include modulation, interference, throughput, bandwidth, power consumption, signal subcarrier subsets are identified in a manner designed to achieve a certain goal. Those goals may include maximizing throughput or performance, minimizing power consumption, meeting minimum bandwidth requirements for certain power line device pairs, or other similar goals. One

example method may be to identify signal subcarriers in a manner designed to achieve the aggregate maximum modulation across all PLC devices of the PLC network. Many other methods may be used, alone or in combination with others, to perform the actual identification of subcarriers. In some implementations, each subcarrier is included in only one of the identified subsets.

[0036] For example, in some implementations, a bandwidth value may be obtained for each pair of power line devices. The bandwidth value may be provided by each corresponding power line device pair or provided by a third party user or device. In some implementations the bandwidth value is an estimated bandwidth value generated based on the number of modulated bits identified for some or all of the signal subcarriers. In situations where estimated bandwidth is obtained or generated, subcarrier subsets may be identified based on the estimated bandwidth, e.g., in a manner designed to maximize bandwidth.

[0037] In some implementations, based on bandwidth requirements and the tonemaps provided by PLC device pairs, candidate subsets of the signal subcarriers may be identified, and subcarrier subsets may be identified from the candidate subsets. For example, candidate subsets may be recursively identified in a manner designed to select candidate subsets for each pair of PLC devices that would meet bandwidth requirement provided by or calculated for the corresponding pairs of PLC devices. The actual subsets identified, e.g., for allocation to the PLC device pairs, may be selected from the candidate subsets, e.g., in a manner designed to ensure all PLC device pairs are provided with signal carrier subsets that allow them to meet certain bandwidth requirements.

[0038] Each of the identified subcarrier subsets is allocated to a corresponding one of the power line device pairs (406). The allocation may cause, for example, the power line devices included in the device pairs to communicate with each other only across those signal subcarriers. In some implementations, the allocation includes providing instructions to power line devices. In some implementations, each power line device may have its own instructions to restrict communications to particular subcarriers in response to receiving an allocation.

[0039] While the method 400 is described with respect to a power line device or single computing device, other computing devices or multiple computing devices may also be used for performing some or all of the above features. For example, a server computer may collect tonemaps and perform the subcarrier subset identification, while a particular power line adapter receives the subsets and distributes the subset allocation data to other power line adapters.

[0040] FIG. 5 is a flowchart of an example method 500 for allocating subcarriers in a power line network. The method 500 may be performed by a computing device, such as a computing device described in FIG. 1, e.g., in the form of a power line adapter. Other computing devices may also be used to execute method 500. Method 500 may be implemented in the form of executable instructions stored on a machine-readable storage medium, such as the storage medium 130, and/or in the form of electronic circuitry, such as an FPGA or ASIC.

[0041] A first power line device obtains first physical layer feedback that includes a first tonemap specifying, for each of a plurality of signal subcarriers, a first number of modulated bits for communications between the first power line device and a second power line device (502). For example, a power line adapter may generate, or obtain from its paired power line adapter, a tonemap showing modulated bits per subcarrier for communications between the power line adapter and its paired adapter.

[0042] The first power line device obtains second physical layer feedback that includes a second tonemap specifying, for each of the signal subcarriers, a second number of modulated bits for communications between a second pair of power line devices that does not include the first power line device or second power line device (504). For example, the power line adapter may obtain a tonemap from another different adapter that is also part of the PLC network, e.g., a third adapter that is communicating with a fourth adapter. In this example, there are four power line devices forming two distinct pairs operating on the same PLC network, e.g., in a home or office, and one power line adapter has obtained a tonemap for each pair.

[0043] Based on the first tonemap and second tonemap, a first and second subset of the signal subcarriers are identified (506). Using the example above, the power line adapter may perform the identification of signal subcarrier subsets, e.g., using any of the methods described above. In some implementations, each signal subcarrier is included in only one subset.

[0044] Instructions are provided for the second pair of power line devices to use the second subset of signal subcarriers for future power line network communications (508). For example, the power line adapter may send to one of the devices included in the second pair of power line adapters, or cause to be sent to using a third party computing device, data that identifies the second subset of signal subcarriers.

[0045] The first subset of signal subcarriers are used to communicate with the second power line device (510). For example, the power line adapter, after instructing the second pair of PLC devices on the PLC network to communicate using the signal subcarriers of the second subset, may communicate with its paired adapter using the subcarriers of the first subset. This allocation is designed to ensure that the PLC device pairs do not compete over signal subcarriers, which may prevent transmission of data between one pair of devices until the other pair of devices is finished. By restricting the subcarriers used, both pairs of PLC devices may communicate concurrently across different subcarriers, which may reduce the likelihood of delays in transmitting data across the PLC network.

[0046] While the method 500 is described with respect to a power line device, other computing devices or multiple computing devices may also be used for performing some or all of the features. For example, in PLC networks with multiple pairs of power line devices, multiple power line adapters may be used to identify signal carrier subsets and/or provide allocation instructions to other power line device pairs.

[0047] The foregoing disclosure describes a number of example implementations for allocating subcarriers in power line networks. As detailed above, examples provide a mechanism for allocating subcarriers to power line device pairs using tonemaps produced by power line devices.

CLAIMS

We claim:

1. A computing device for allocating subcarriers in power line networks, the computing device comprising:

a hardware processor; and

a data storage device storing instructions that, when executed by the hardware processor, cause the hardware processor to:

obtain, for a first pair of power line devices, first physical layer feedback that includes a first tonemap specifying, for each of a plurality of signal subcarriers, a first number of modulated bits;

obtain, for a second pair of power line devices, second physical layer feedback that includes a second tonemap specifying, for each of the plurality of signal subcarriers, a second number of modulated bits;

identify, based on the first tonemap and second tonemap, a first subset of the plurality of signal subcarriers and a second subset of the plurality of signal subcarriers;

allocate the first subset of subcarriers to the first pair of power line devices; and

allocate the second subset of subcarriers to the second pair of power line devices.

2. The computing device of claim 1, wherein each subcarrier included in the first subset is different from each subcarrier included in the second subset.

3. The computing device of claim 1, wherein the instructions further cause the hardware processor to:

obtain, for the first pair of power line devices, a first bandwidth value;

obtain, for the second pair of power line devices, a second bandwidth value, and

wherein the first subset and second subset are identified based on the first and second bandwidth values.

4. The computing device of claim 1, wherein the instructions further cause the hardware processor to:

generate, based on modulated bits identified for the first subset of subcarriers, a first estimated bandwidth for the first pair of power line devices;

generate, based on modulated bits identified for the second subset of subcarriers, a second estimated bandwidth for the second pair of power line devices, and

wherein the first subset and second subset are identified based on the first and second estimated bandwidth.

5. The computing device of claim 1, wherein the instructions further cause the hardware processor to:

obtain, for the first pair of power line devices, a first bandwidth requirement;

identify, based on the first bandwidth requirement and the first tonemap, a plurality of first candidate subsets of the plurality of signal subcarriers;

obtain, for the second pair of power line devices, a second bandwidth requirement; and

identify, based on the second bandwidth requirement and the second tonemap, a plurality of second candidate subsets of the plurality of signal subcarriers, and wherein:

the first subset is identified from the plurality of first candidate subsets, and

the second subset is identified from the plurality of second candidate subsets.

6. A non-transitory machine-readable storage medium encoded with instructions executable by a hardware processor of a computing device for allocating subcarriers in power line networks, the machine-readable storage medium comprising instructions to cause the hardware processor to:

obtain, for each of a plurality of power line device pairs, physical layer

feedback that includes a tonemap specifying, for each of a plurality of signal subcarriers, a number of modulated bits;

identify, for each of the plurality of power line device pairs and based on the tonemaps, a subset of the plurality of signal subcarriers; and

allocate, to each of the plurality of power line device pairs, a corresponding one of the identified subsets of the plurality of signal subcarriers.

7. The storage medium of claim 6, wherein each subcarrier is included in only one of the identified subsets allocated to the power line devices.

8. The storage medium of claim 6, wherein the instructions further cause the hardware processor to:

obtain, for each pair of power line devices, a bandwidth value, and

wherein each subset is identified based on the bandwidth values.

9. The storage medium of claim 6, wherein the instructions further cause the hardware processor to:

generate, for each pair of power line devices, an estimated bandwidth based on modulated bits identified for the identified subset of subcarriers for the pair of power line devices, and

wherein each subset is identified for each pair of power line devices based on the estimated bandwidth that corresponds to the pair of power line devices.

10. The storage medium of claim 6, wherein the instructions further cause the hardware processor to:

obtain, for each pair of power line devices, a bandwidth requirement; and

identify, based on the bandwidth requirements and the tonemaps, a plurality of candidate subsets of the plurality of signal subcarriers, and

wherein each subset is identified from the plurality of candidate subsets.

11. A method for allocating subcarriers in power line networks, implemented

by a hardware processor, the method comprising:

obtaining, by a first power line device, first physical layer feedback that includes a first tonemap specifying, for each of a plurality of signal subcarriers, a first number of modulated bits for communications between the first power line device and a second power line device;

obtaining, by the first power line device, second physical layer feedback that includes a second tonemap specifying, for each of the plurality of signal subcarriers, a second number of modulated bits for communications between a second pair of power line devices that does not include the first power line device or second power line device;

identifying, based on the first tonemap and second tonemap, a first subset of the plurality of signal subcarriers and a second subset of the plurality of signal subcarriers;

providing instructions for the second pair of power line devices to use the second subset of signal subcarriers for future power line network communications; and

using the first subset of signal subcarriers to communicate with the second power line device.

12. The method of claim 11, wherein each signal subcarrier included in the first subset is different from each signal subcarrier included in the second subset.

13. The method of claim 11, further comprising:

obtain a first bandwidth value for communications between the first and second power line devices;

obtain a second bandwidth value for communications between the second pair of power line devices, and

wherein the first subset and second subset are identified based on the first and second bandwidth values.

14. The method of claim 11, further comprising:

generating, based on modulated bits identified for the first subset of signal subcarriers, a first estimated bandwidth for communications between the first and second power line devices;

generating, based on modulated bits identified for the second subset of signal subcarriers, a second estimated bandwidth for communications between the second pair of power line devices, and

wherein the first subset and second subset are identified based on the first and second estimated bandwidth.

15. The method of claim 11, further comprising:

obtaining, for the first and second power line devices, a first bandwidth requirement;

identifying, based on the first bandwidth requirement and the first tonemap, a plurality of first candidate subsets of the plurality of signal subcarriers;

obtaining, for the second pair of power line devices, a second bandwidth requirement; and

identifying, based on the second bandwidth requirement and the second tonemap, a plurality of second candidate subsets of the plurality of signal subcarriers, and wherein:

the first subset is identified from the plurality of first candidate subsets, and

the second subset is identified from the plurality of second candidate subsets.

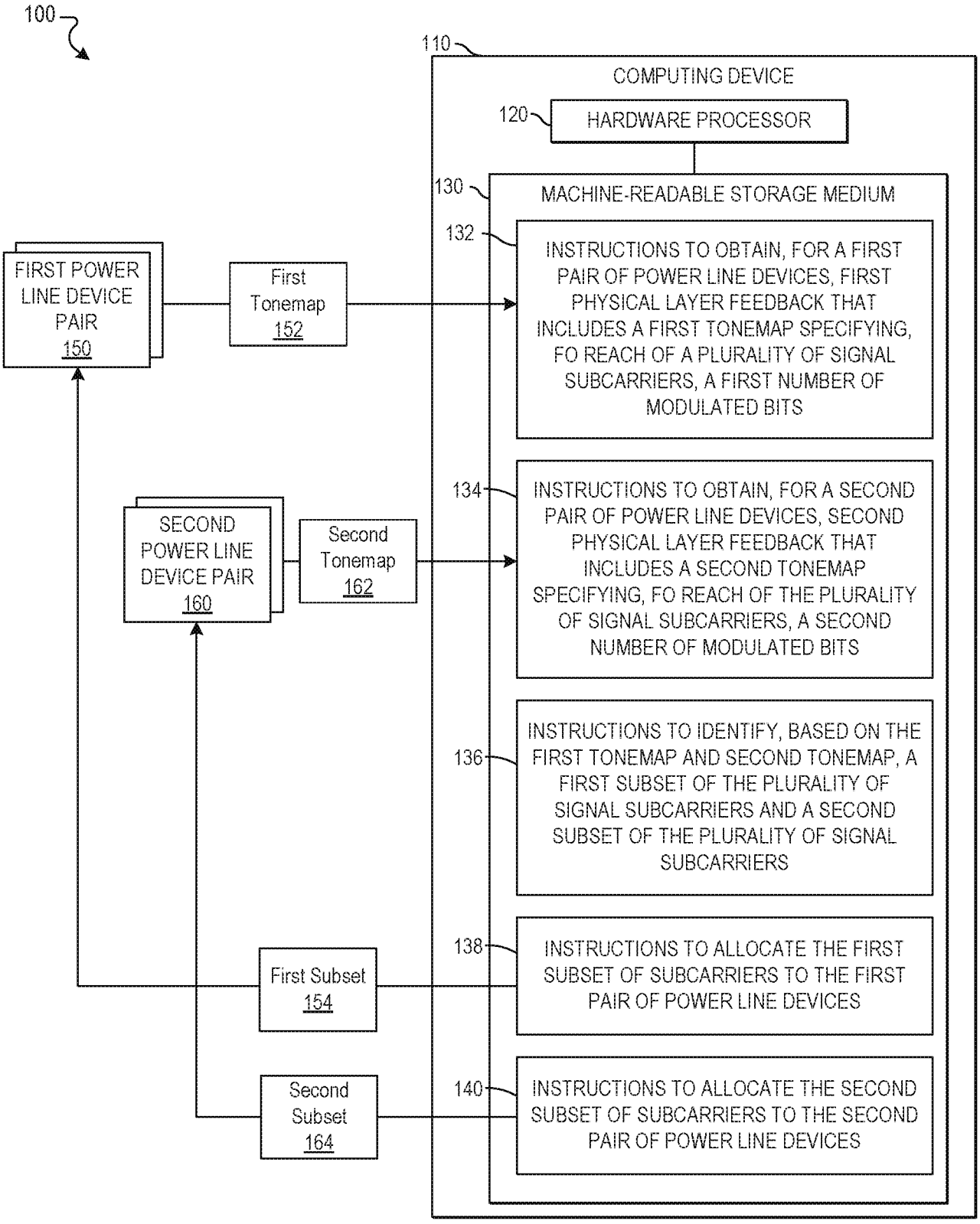
100
110
COMPUTING DEVICE
120
HARDWARE PROCESSOR
130
MACHINE-READABLE STORAGE MEDIUM
132
INSTRUCTIONS TO OBTAIN, FOR A FIRST PAIR OF POWER LINE DEVICES, FIRST PHYSICAL LAYER FEEDBACK THAT INCLUDES A FIRST TONEMAP SPECIFYING, FO REACH OF A PLURALITY OF SIGNAL SUBCARRIERS, A FIRST NUMBER OF MODULATED BITS
134
INSTRUCTIONS TO OBTAIN, FOR A SECOND PAIR OF POWER LINE DEVICES, SECOND PHYSICAL LAYER FEEDBACK THAT INCLUDES A SECOND TONEMAP SPECIFYING, FO REACH OF THE PLURALITY OF SIGNAL SUBCARRIERS, A SECOND NUMBER OF MODULATED BITS
136
INSTRUCTIONS TO IDENTIFY, BASED ON THE FIRST TONEMAP AND SECOND TONEMAP, A FIRST SUBSET OF THE PLURALITY OF SIGNAL SUBCARRIERS AND A SECOND SUBSET OF THE PLURALITY OF SIGNAL SUBCARRIERS
138
INSTRUCTIONS TO ALLOCATE THE FIRST SUBSET OF SUBCARRIERS TO THE FIRST PAIR OF POWER LINE DEVICES
140
INSTRUCTIONS TO ALLOCATE THE SECOND SUBSET OF SUBCARRIERS TO THE SECOND PAIR OF POWER LINE DEVICES
FIRST POWER LINE DEVICE PAIR 150
First Tonemap 152
SECOND POWER LINE DEVICE PAIR 160
Second Tonemap 162
First Subset 154
Second Subset 164

FIG. 1

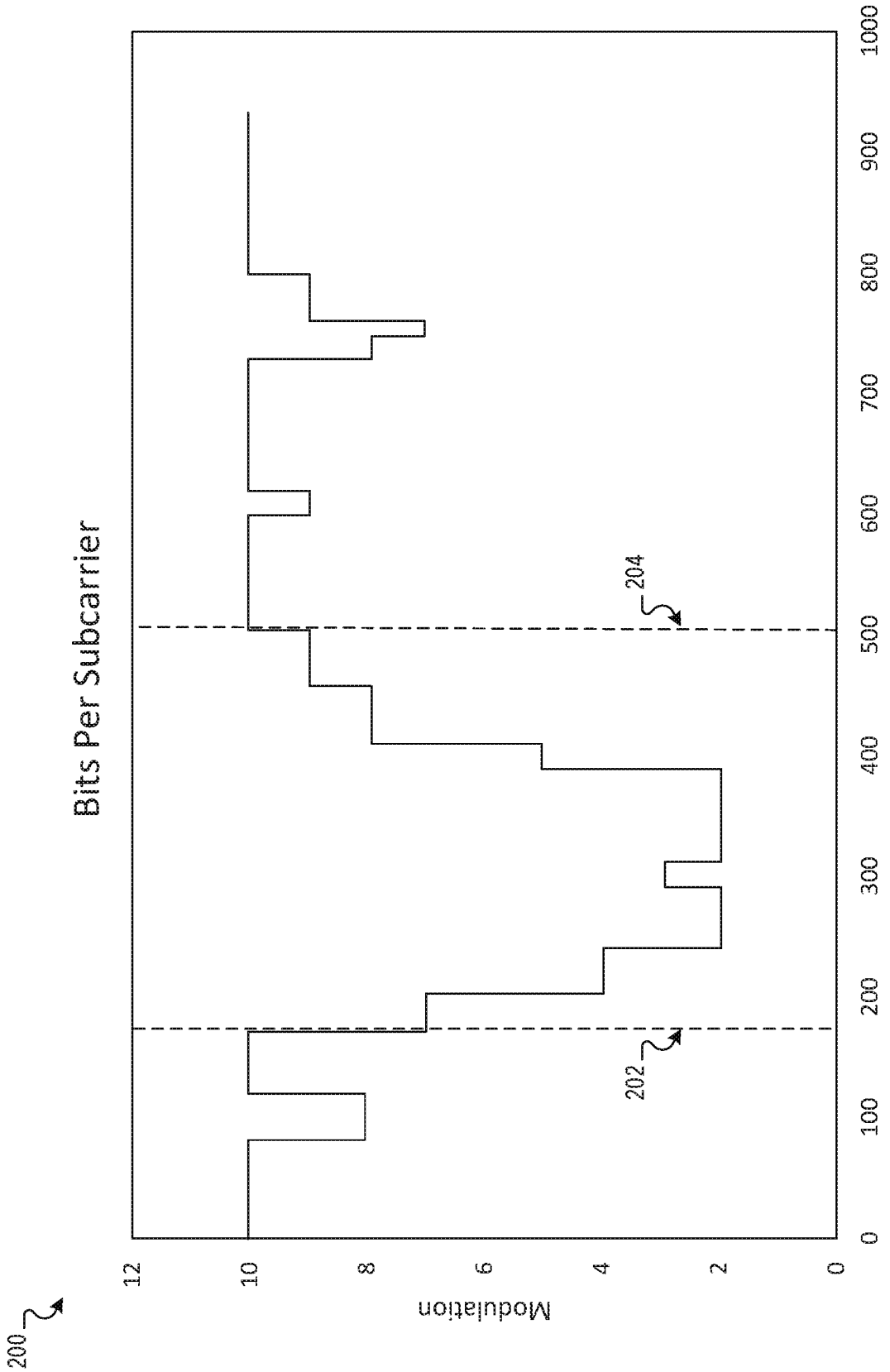
200
Bits Per Subcarrier
Modulation
0
2
4
6
8
10
12
Subcarrier IDs
0
100
200
300
400
500
600
700
800
900
1000
202
204

FIG. 2A

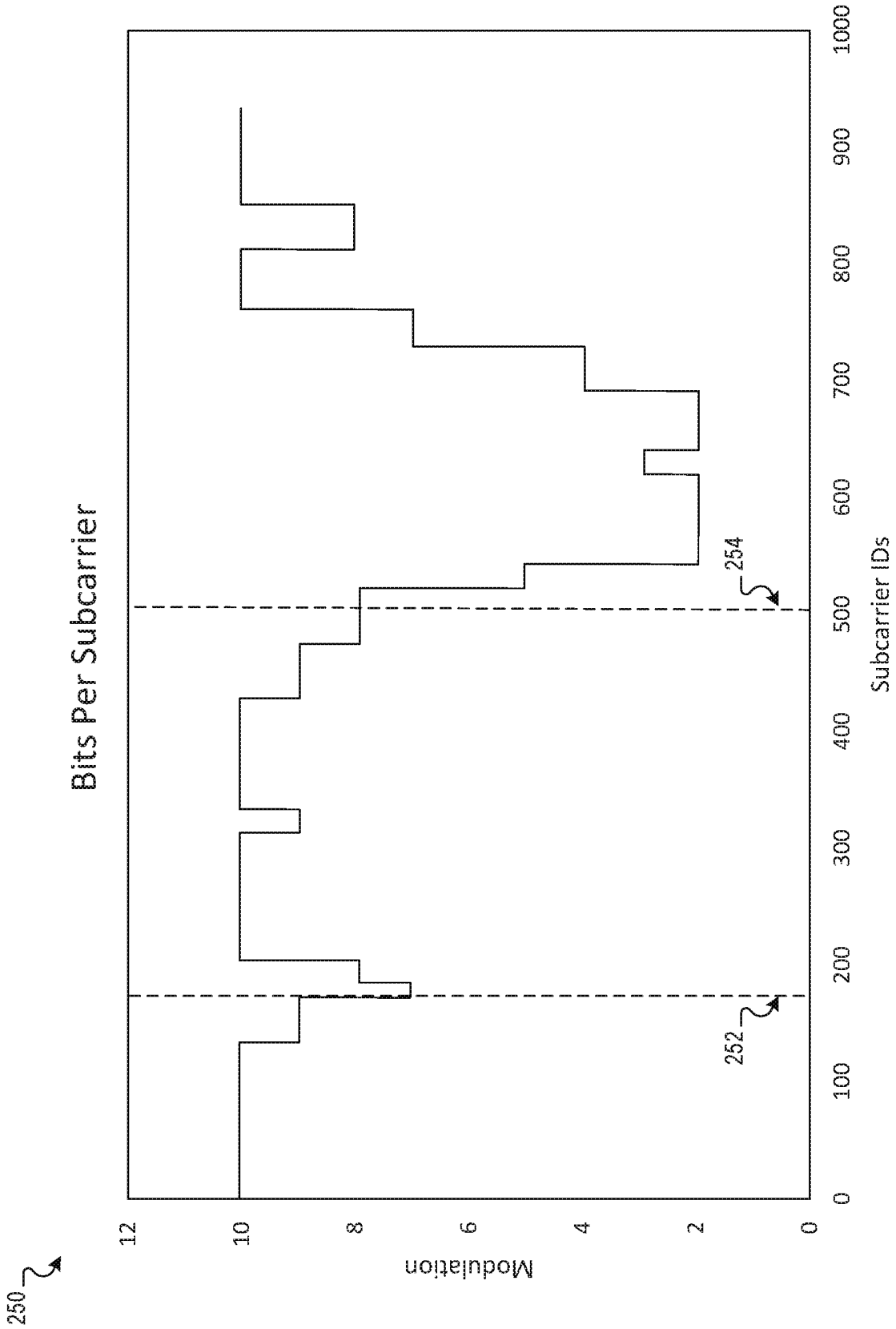
250
Bits Per Subcarrier
Modulation
0
2
4
6
8
10
12
Subcarrier IDs
0
100
200
300
400
500
600
700
800
900
1000
252
254

FIG. 2B

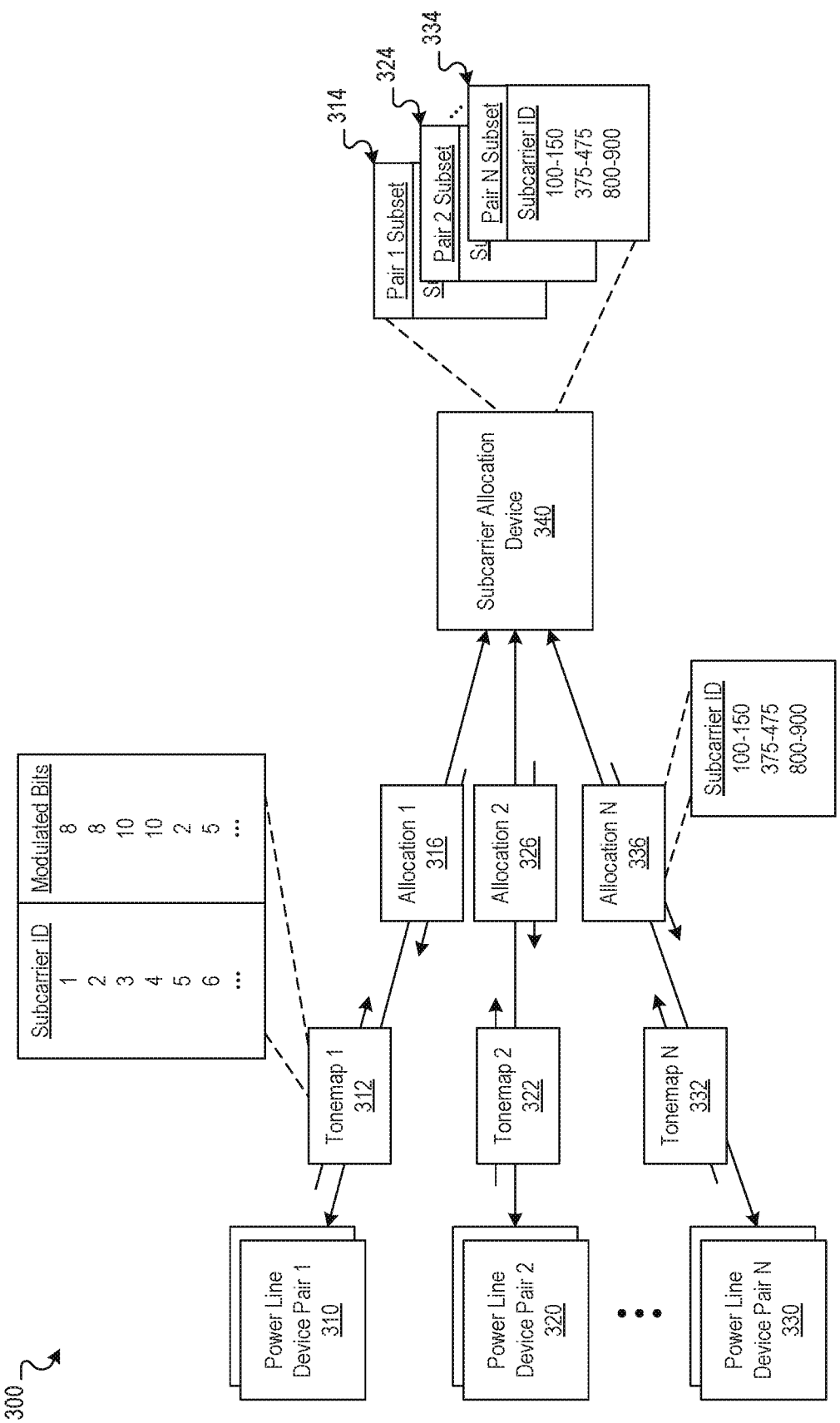
300
Power Line Device Pair 1 310
Power Line Device Pair 2 320
Power Line Device Pair N 330
Tonemap 1 312
Tonemap 2 322
Tonemap N 332
Subcarrier ID
1
2
3
4
5
6
...
Modulated Bits
8
8
10
10
2
5
...
Allocation 1 316
Allocation 2 326
Allocation N 336
Subcarrier ID
100-150
375-475
800-900
Subcarrier Allocation Device 340
314
324
334
Pair 1 Subset
Pair 2 Subset
Pair N Subset
Subcarrier ID
100-150
375-475
800-900

FIG. 3

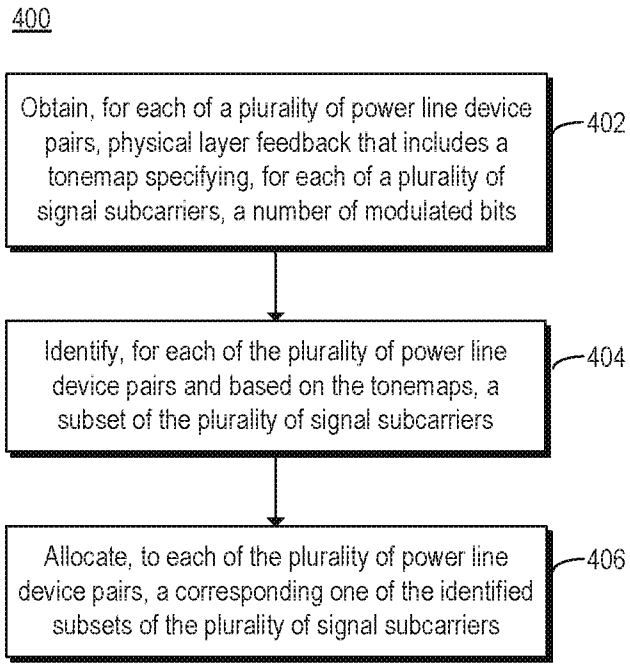
400
Obtain, for each of a plurality of power line device pairs, physical layer feedback that includes a tonemap specifying, for each of a plurality of signal subcarriers, a number of modulated bits
402
Identify, for each of the plurality of power line device pairs and based on the tonemaps, a subset of the plurality of signal subcarriers
404
Allocate, to each of the plurality of power line device pairs, a corresponding one of the identified subsets of the plurality of signal subcarriers
406

FIG. 4

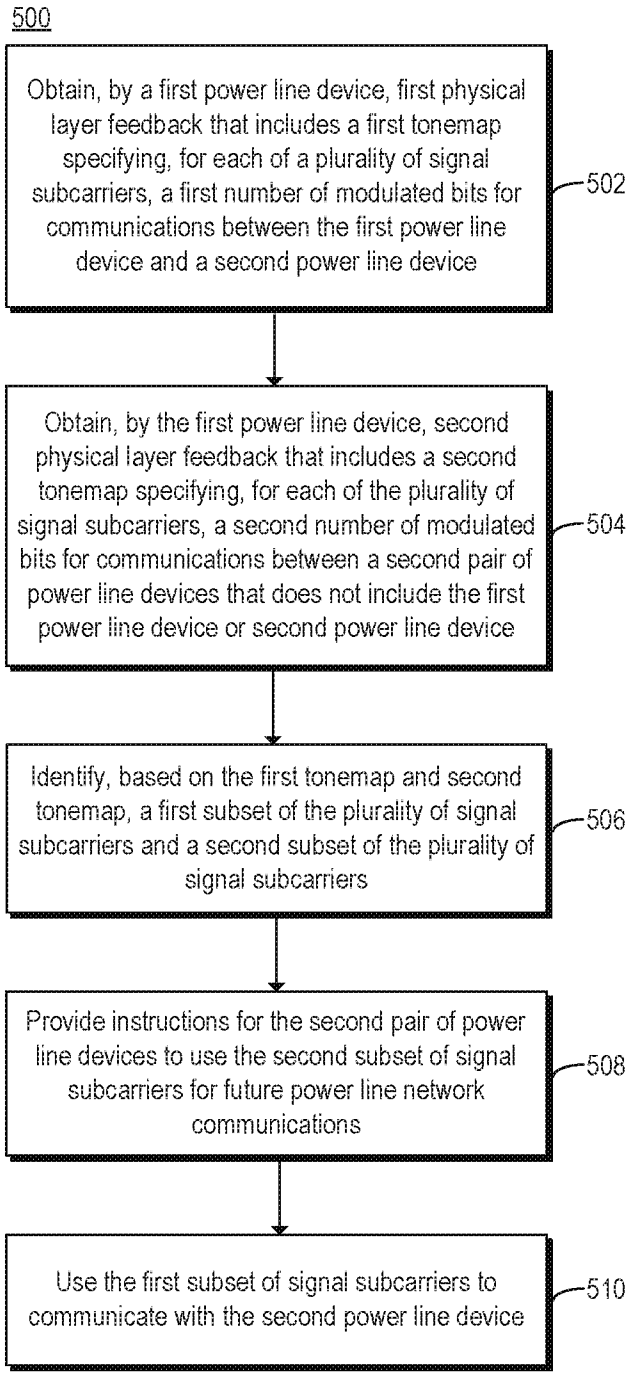
500
Obtain, by a first power line device, first physical layer feedback that includes a first tonemap specifying, for each of a plurality of signal subcarriers, a first number of modulated bits for communications between the first power line device and a second power line device
502
Obtain, by the first power line device, second physical layer feedback that includes a second tonemap specifying, for each of the plurality of signal subcarriers, a second number of modulated bits for communications between a second pair of power line devices that does not include the first power line device or second power line device
504
Identify, based on the first tonemap and second tonemap, a first subset of the plurality of signal subcarriers and a second subset of the plurality of signal subcarriers
506
Provide instructions for the second pair of power line devices to use the second subset of signal subcarriers for future power line network communications
508
Use the first subset of signal subcarriers to communicate with the second power line device
510

FIG. 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2016/025316

A. CLASSIFICATION OF SUBJECT MATTER

H04L 27/26(2006.01)i, H04L 5/00(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04L 27/26; H04L 5/00; H04B 3/54; H04L 27/28; H04L 12/413; H04B 3/00; H04L 12/721

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords: power line communication, tonemap, subcarrier, feedback, allocate

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 8711953 B1 (SONY CORPORATION) 29 April 2014 See column 3, lines 45-48; column 6, lines 46-62; column 8, lines 27-38; claims 1, 9; and figures 3a, 7.	1-15
A	US 2013-0107974 A1 (SONY CORPORATION) 02 May 2013 See paragraphs [0024]-[0106]; and figures 1A-8.	1-15
A	US 2012-0134430 A1 (YUAN-HWA LI et al.) 31 May 2012 See paragraphs [0025]-[0081]; and figures 1-11.	1-15
A	US 2015-0172073 A1 (TEXAS INSTRUMENTS INCORPORATED) 18 June 2015 See paragraphs [0023]-[0078]; and figures 1-10.	1-15
A	US 2015-0063365 A1 (CISCO TECHNOLOGY, INC.) 05 March 2015 See paragraphs [0018]-[0101]; and figures 1-8.	1-15

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

☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
16 December 2016 (16.12.2016)	**19 December 2016 (19.12.2016)**

Name and mailing address of the ISA/KR
International Application Division
Korean Intellectual Property Office
189 Cheongsa-ro, Seo-gu, Daejeon, 35208, Republic of Korea
Facsimile No. +82-42-481-8578

Authorized officer
LEE, Seoung Young
Telephone No. +82-42-481-3535

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.
PCT/US2016/025316

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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US 2013-0107974 A1	02/05/2013	CN 102687436 A	19/09/2012
		CN 102687436 B	25/11/2015
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