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Barr

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(54) **METHOD AND APPARATUS FOR ASYNCHRONOUS ORTHOGONAL FREQUENCY DIVISION MULTIPLE ACCESS**

(75) Inventor: **David Barr**, San Jose, CA (US)

(73) Assignee: **Entropic Communications, LLC**

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(60) Provisional application No. 61/310,813, filed on Mar. 5, 2010, provisional application No. 61/320,490, filed on Apr. 2, 2010, provisional application No. 61/328,061, filed on Apr. 26, 2010, provisional application No. 61/371,284, filed on Aug. 6, 2010.

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H04L 5/00 (2006.01)
H04L 27/28 (2006.01)

(52) **U.S. Cl.**
CPC ***H04J 4/00*** (2013.01); *H04L 5/0007* (2013.01); *H04L 27/28* (2013.01)

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CPC H04J 4/00; H04L 5/0007; H04L 5/0037; H04L 5/0053; H04L 5/023; H04L 5/0048; H04L 27/28; H04W 16/14
USPC 370/319, 344, 431, 436, 478; 375/260
See application file for complete search history.

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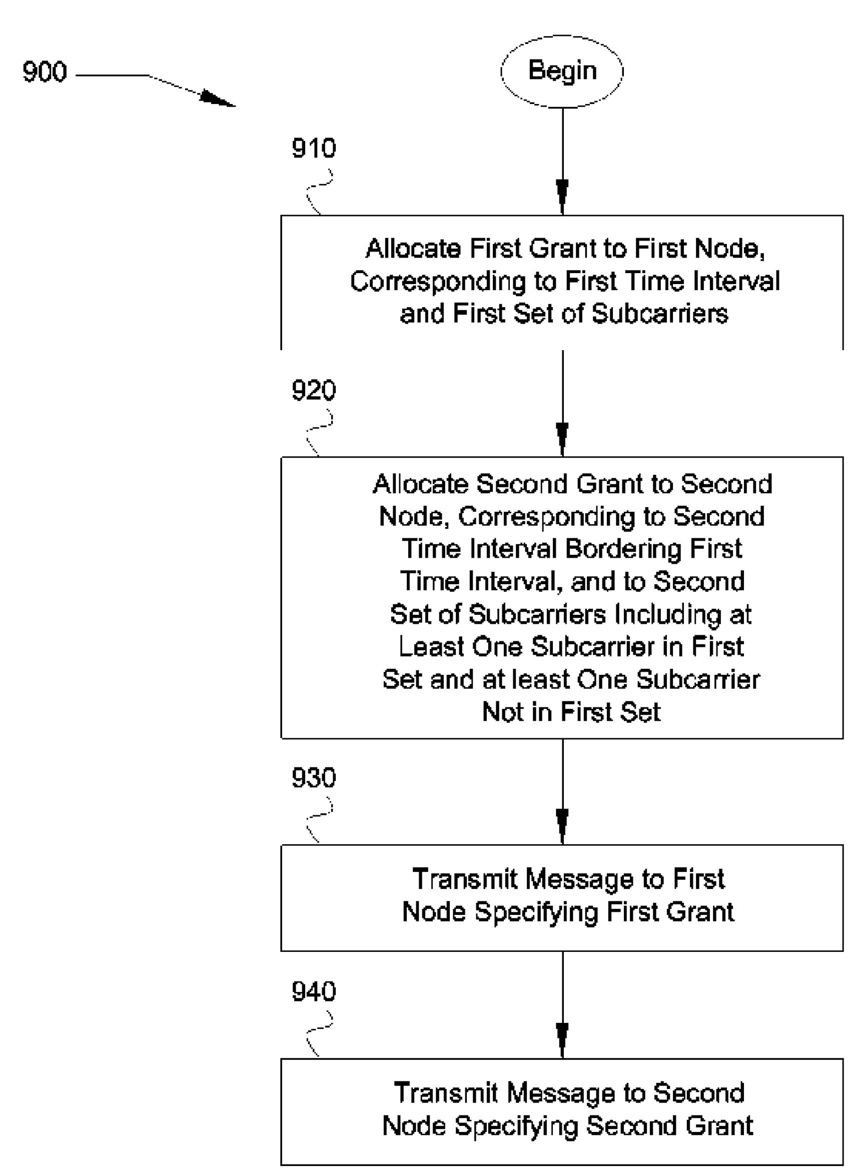
Primary Examiner — Andrew Chriss
Assistant Examiner — Rasha Fayed
(74) *Attorney, Agent, or Firm* — McAndrews, Held & Malloy, Ltd.

(57) **ABSTRACT**

A method of transmitting orthogonal frequency division multiple access (OFDMA) signals includes transmitting, at a first transmitter of a network, a first stream of data having a first number of symbols over a first time interval using a first set of one or more OFDMA subcarriers. At a second transmitter of the network, a second stream of data is transmitted having a second number of symbols over a second time interval, different in duration than the first time interval and overlapping the first time interval. The second burst of data is transmitted using a second set of one or more OFDMA subcarriers. The first time interval and first set of subcarriers define a first time-frequency grant, the second time interval and second set of subcarriers define a second time-frequency grant, and the first and second time-frequency grants are granted by a network coordinator node of the network.

21 Claims, 11 Drawing Sheets



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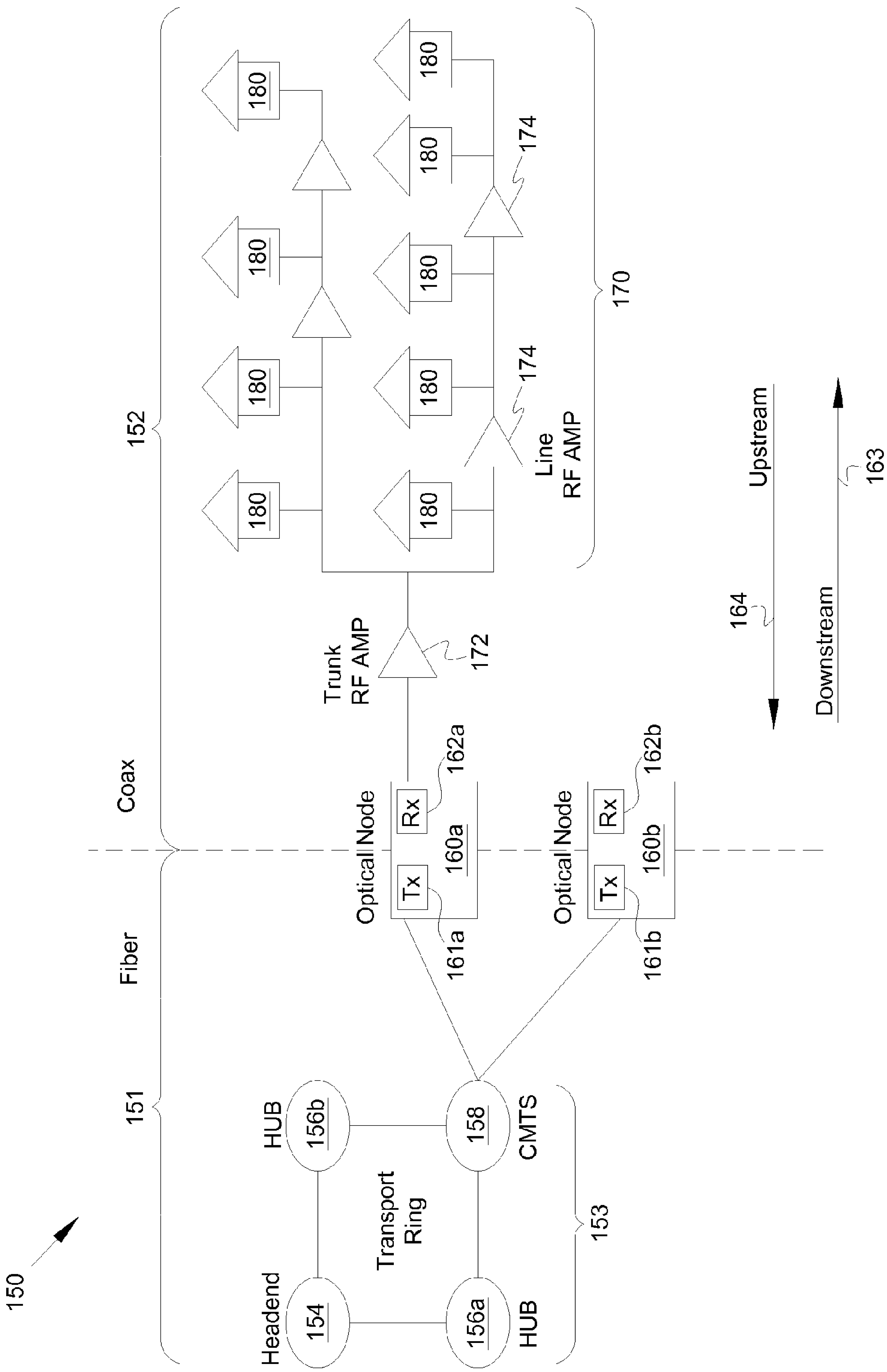

Figure 1A
Prior Art

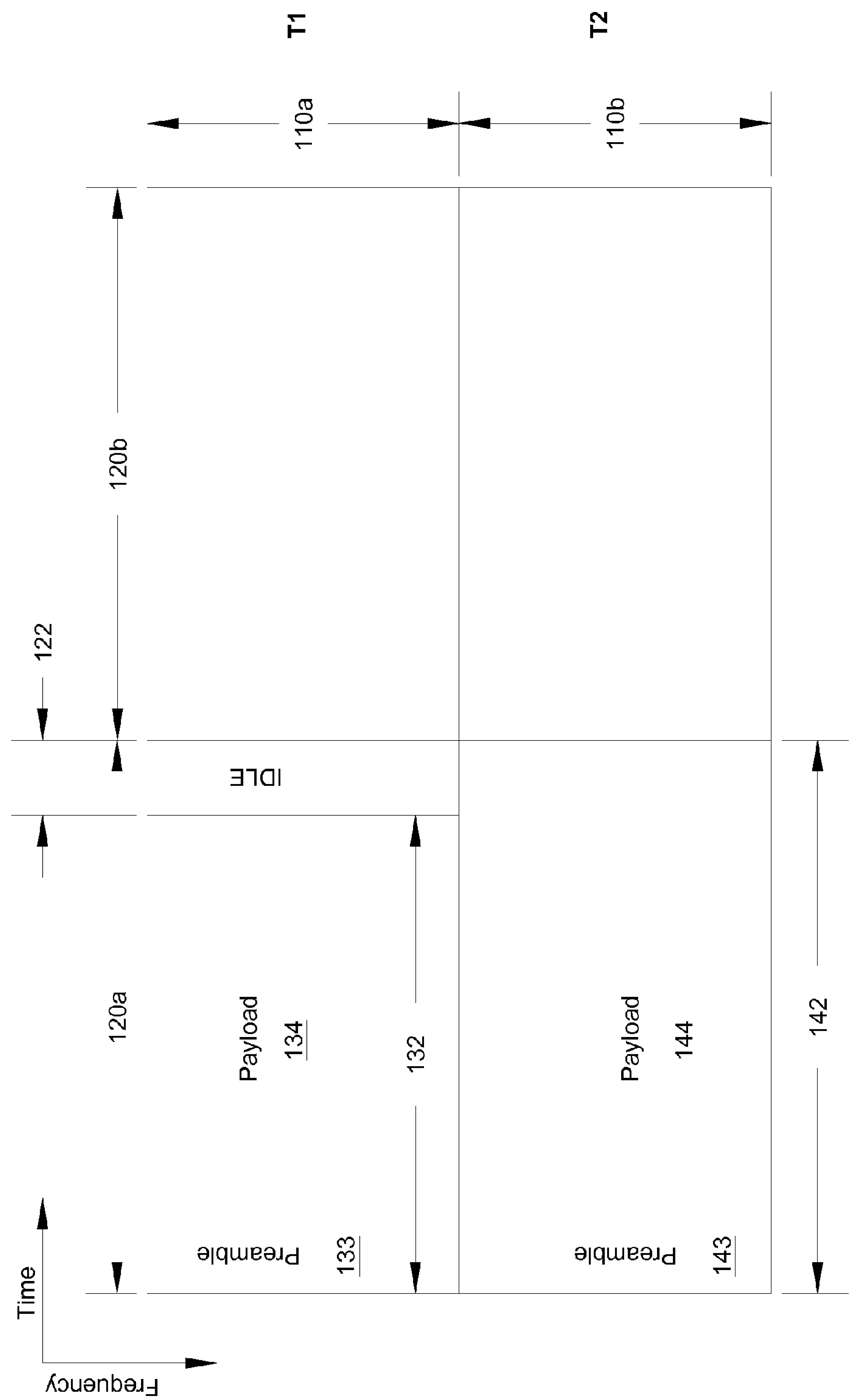

Figure 1B
Prior Art

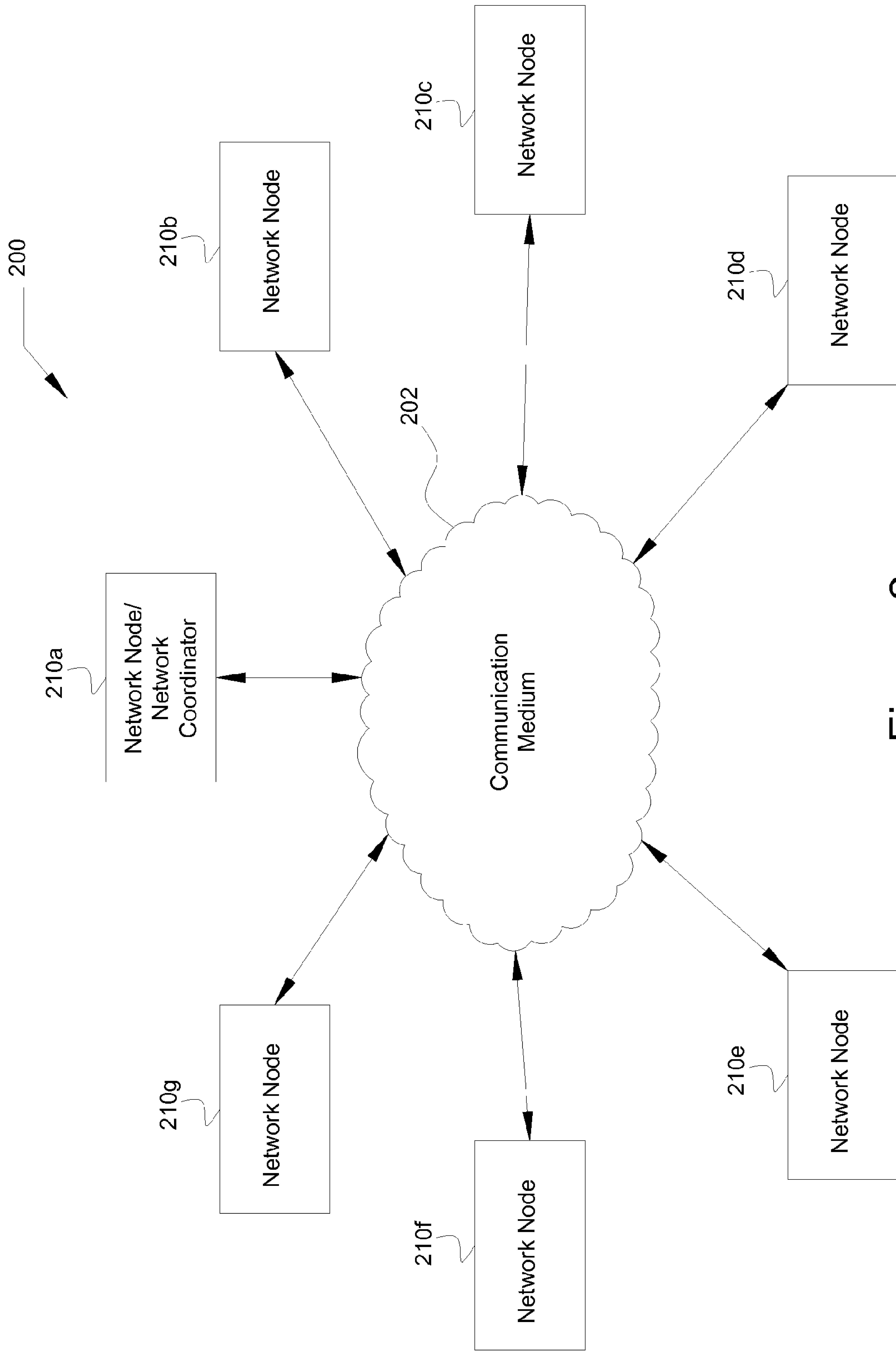
200
202
Communication Medium
210a
Network Node/ Network Coordinator
210b
Network Node
210c
Network Node
210d
Network Node
210e
Network Node
210f
Network Node
210g
Network Node

Figure 2

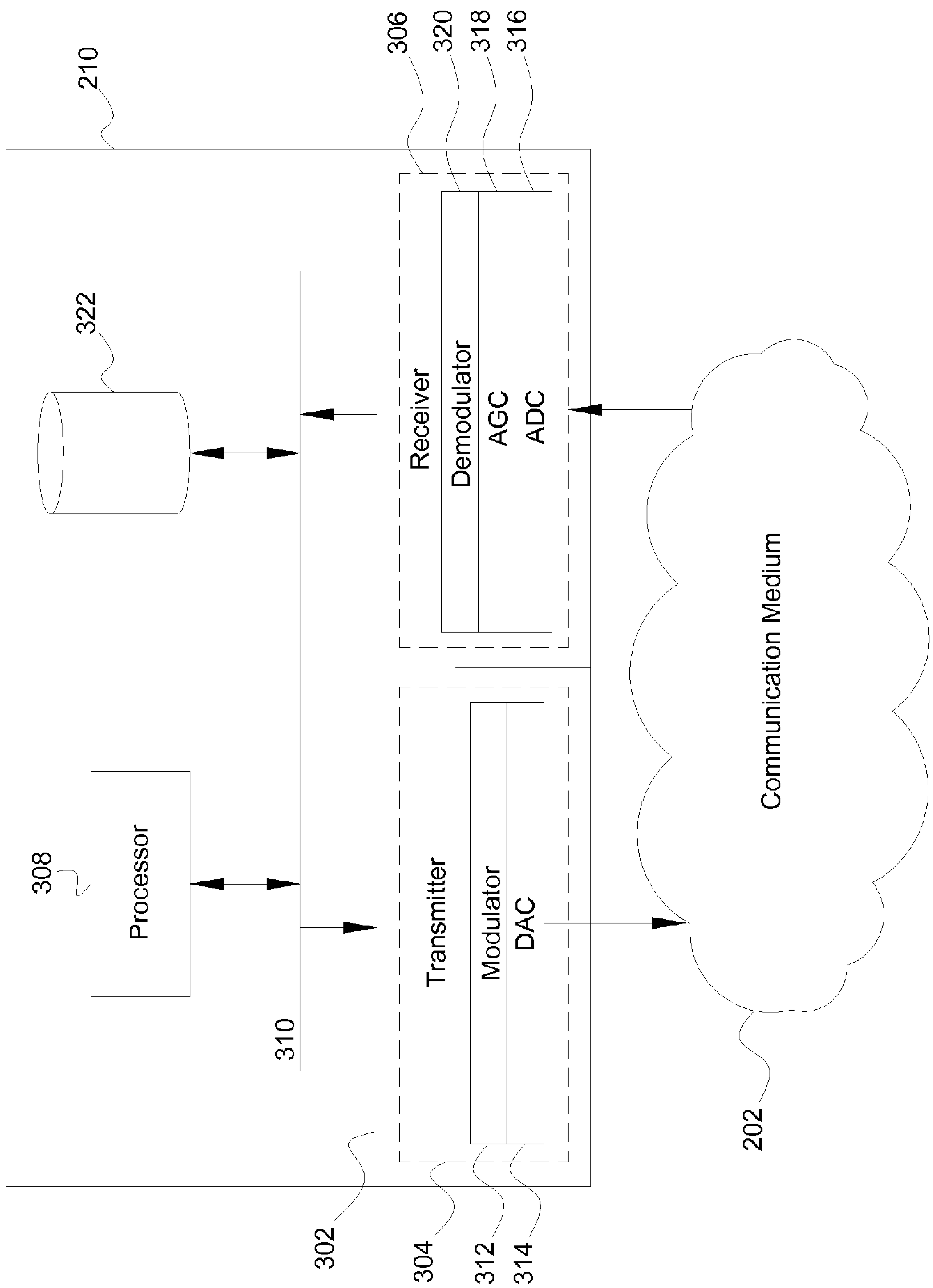
210
322
308
Processor
310
302
306
320
318
316
Receiver
Demodulator
AGC
ADC
Transmitter
Modulator
DAC
304
312
314
Communication Medium
202

Figure 3

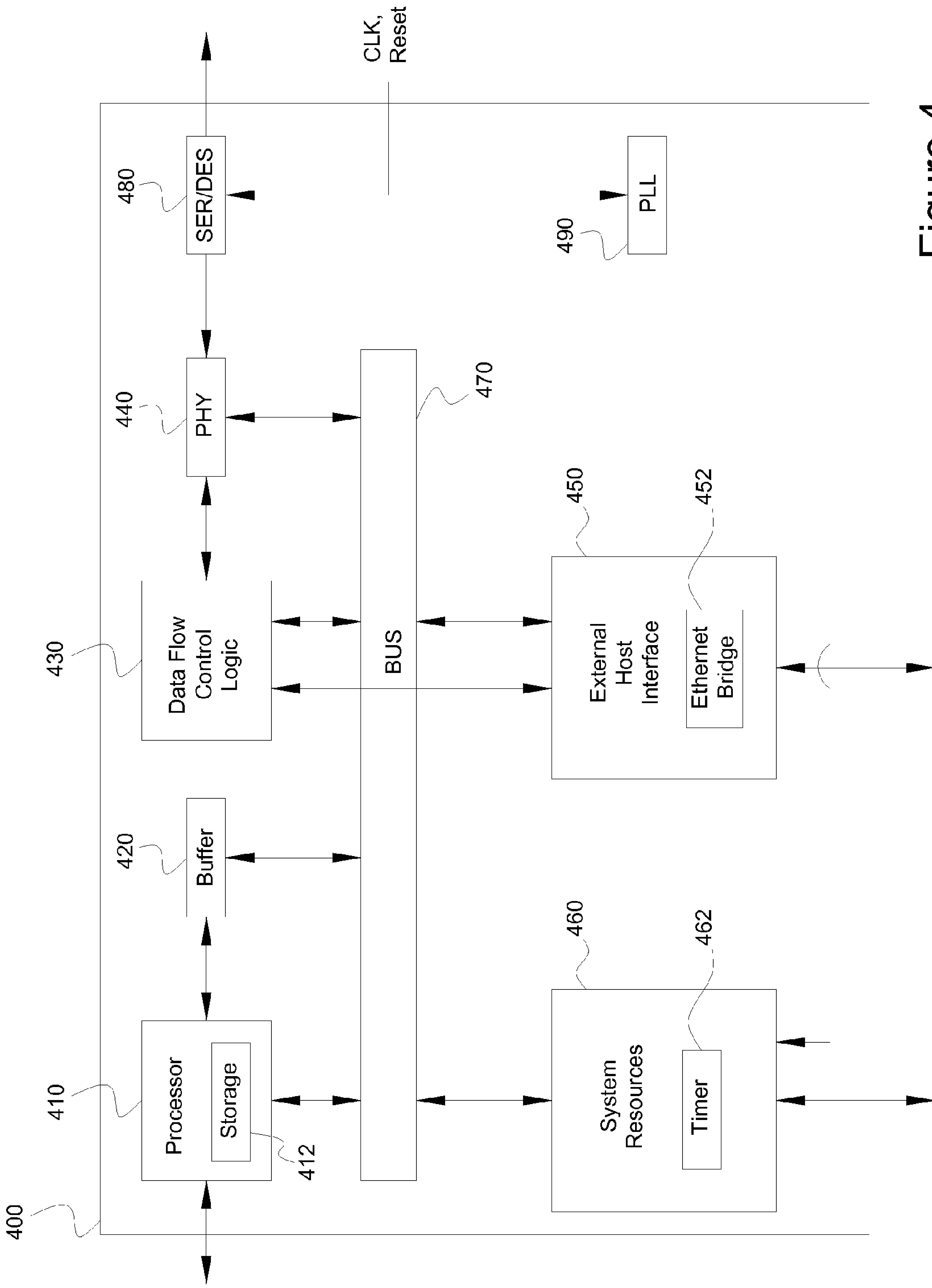
CLK,
Reset
480
SER/DES
490
PLL
440
PHY
470
430
Data Flow
Control
Logic
BUS
450
452
External
Host
Interface
Ethernet
Bridge
420
Buffer
460
462
410
Processor
Storage
412
System
Resources
Timer
400

Figure 4

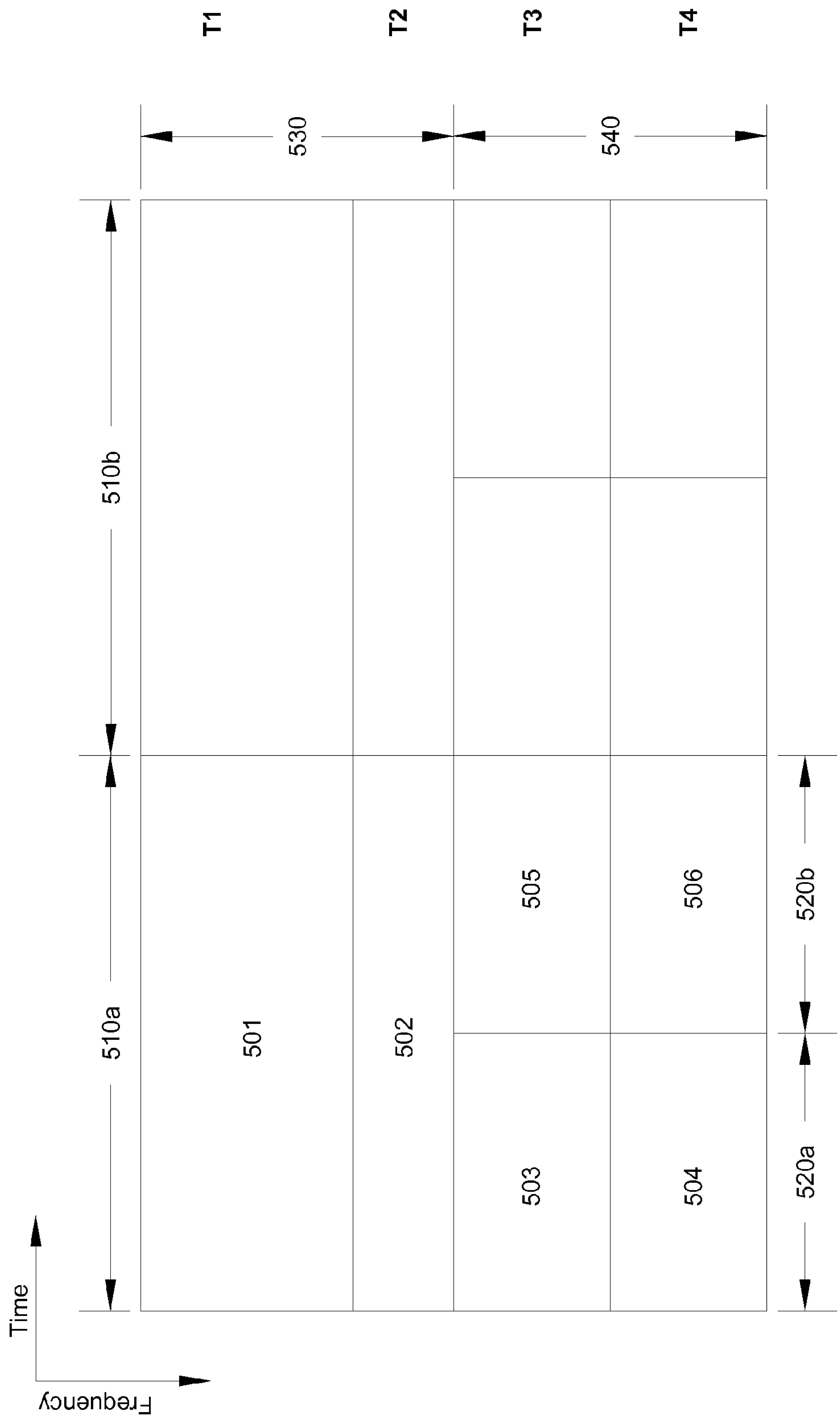
T1
T2
T3
T4
530
540
510b
510a
501
502
503
504
505
506
520a
520b
Time
Frequency

Figure 5A

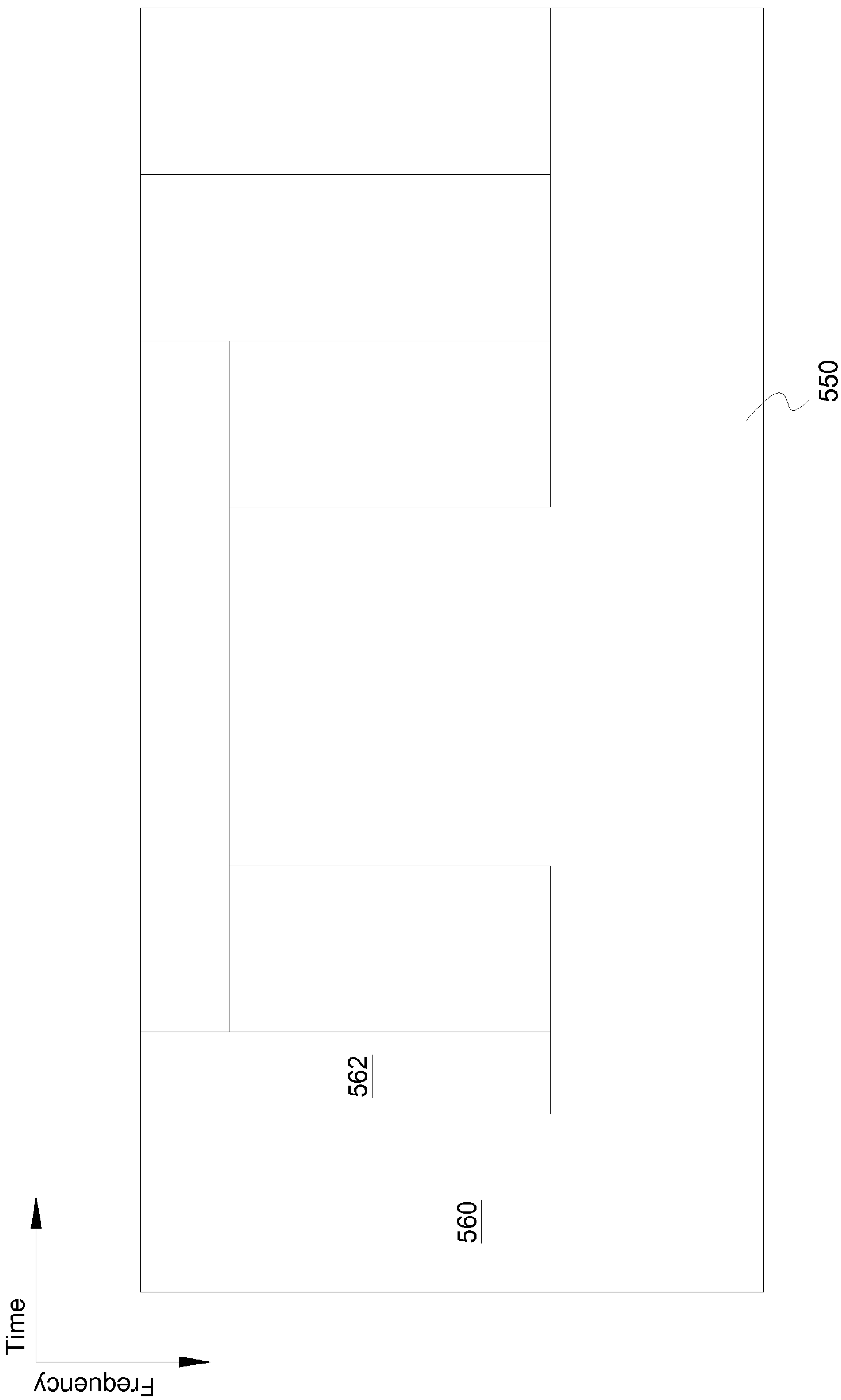

Figure 5B

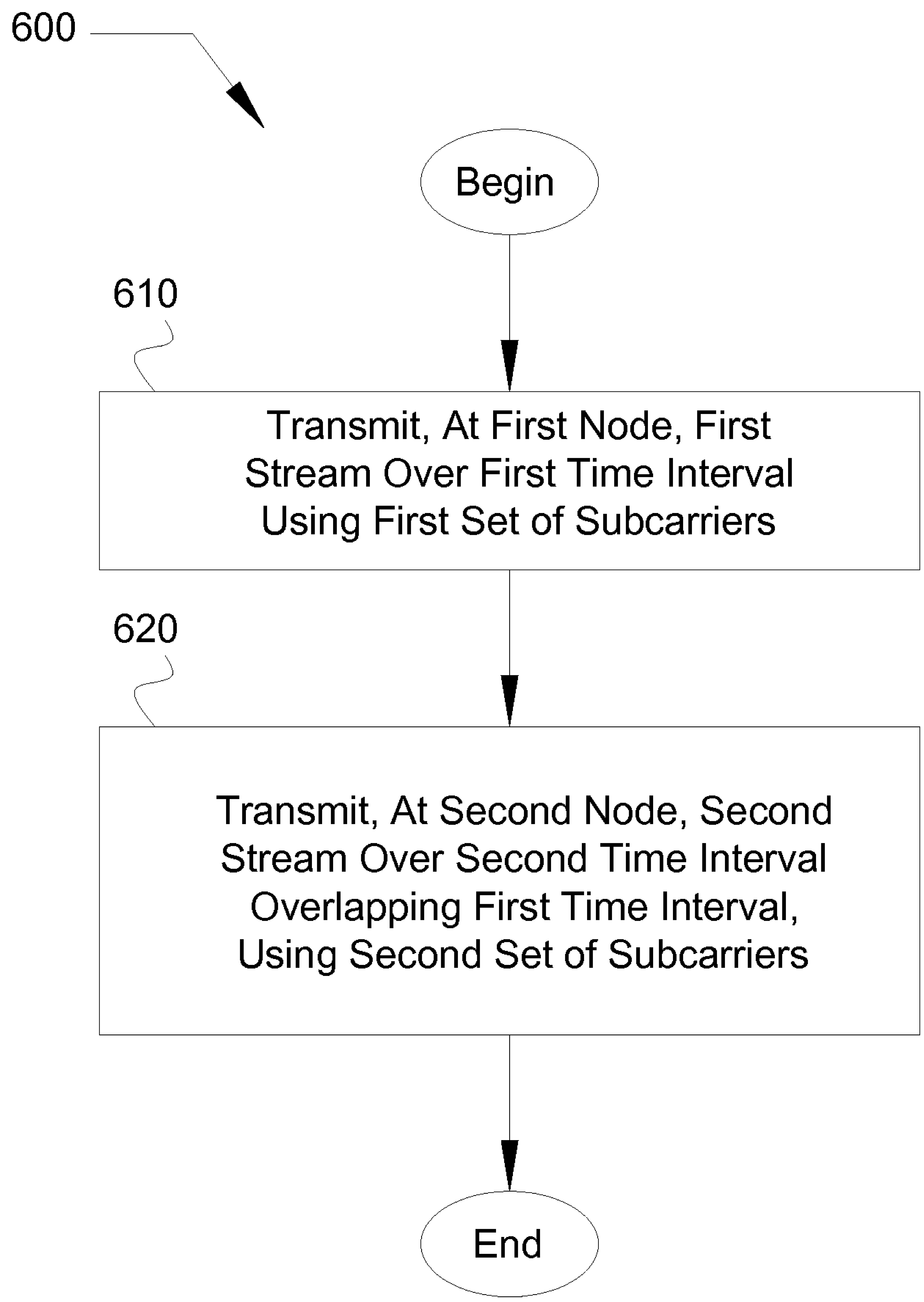
600
Begin
610
Transmit, At First Node, First Stream Over First Time Interval Using First Set of Subcarriers
620
Transmit, At Second Node, Second Stream Over Second Time Interval Overlapping First Time Interval, Using Second Set of Subcarriers
End

Figure 6

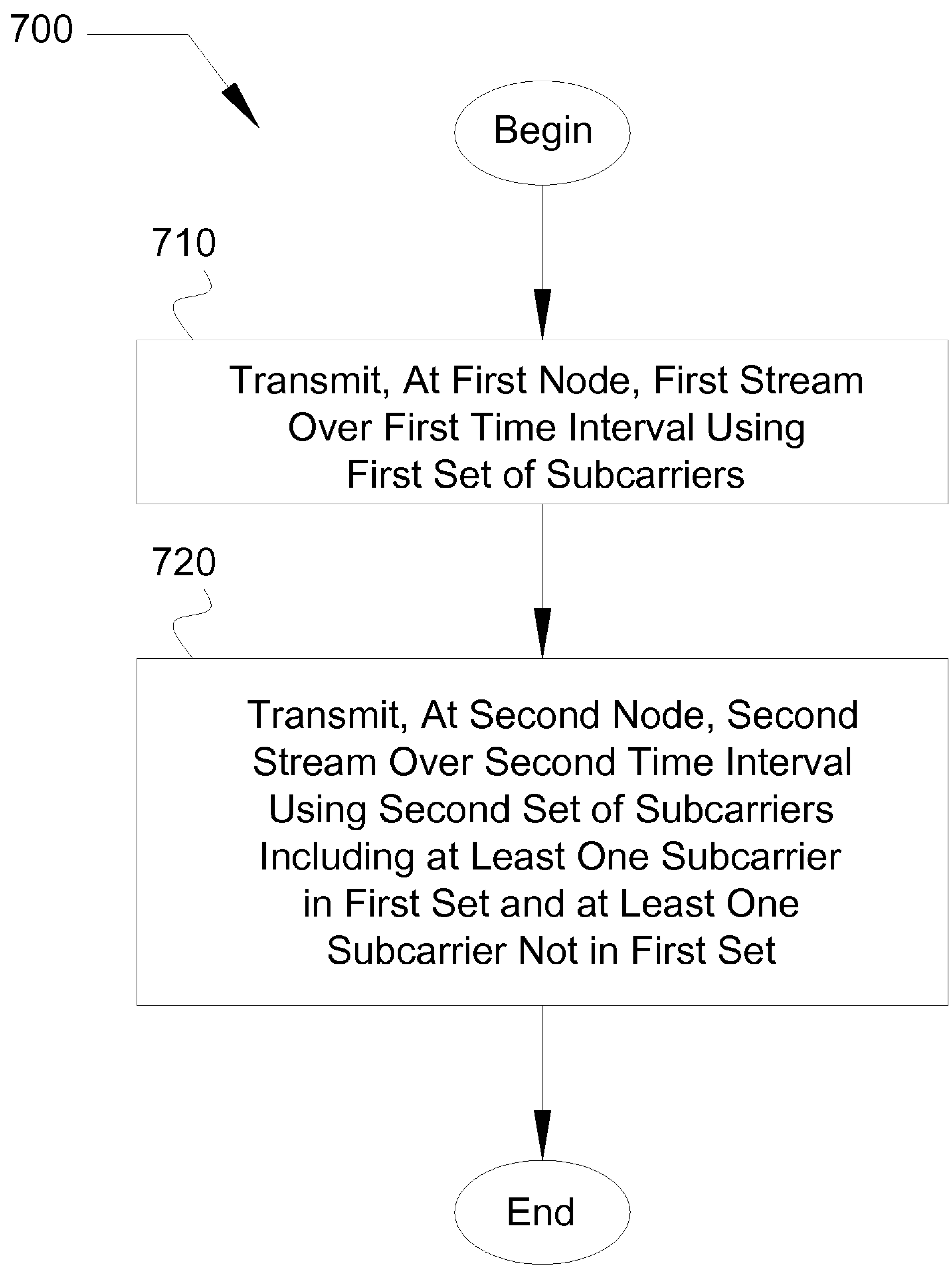
700
Begin
710
Transmit, At First Node, First Stream Over First Time Interval Using First Set of Subcarriers
720
Transmit, At Second Node, Second Stream Over Second Time Interval Using Second Set of Subcarriers Including at Least One Subcarrier in First Set and at Least One Subcarrier Not in First Set
End

Figure 7

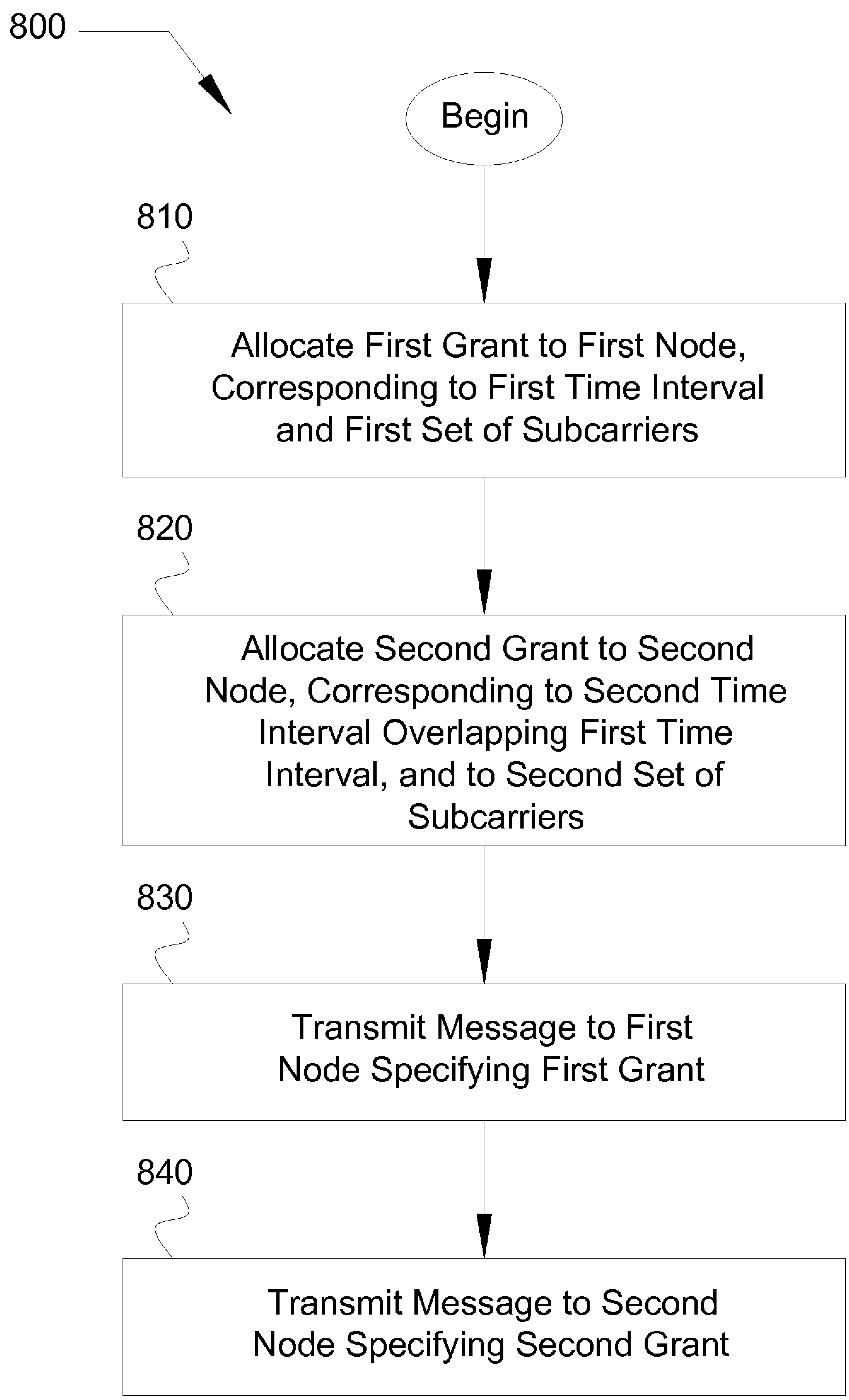
800
Begin
810
Allocate First Grant to First Node, Corresponding to First Time Interval and First Set of Subcarriers
820
Allocate Second Grant to Second Node, Corresponding to Second Time Interval Overlapping First Time Interval, and to Second Set of Subcarriers
830
Transmit Message to First Node Specifying First Grant
840
Transmit Message to Second Node Specifying Second Grant

Figure 8

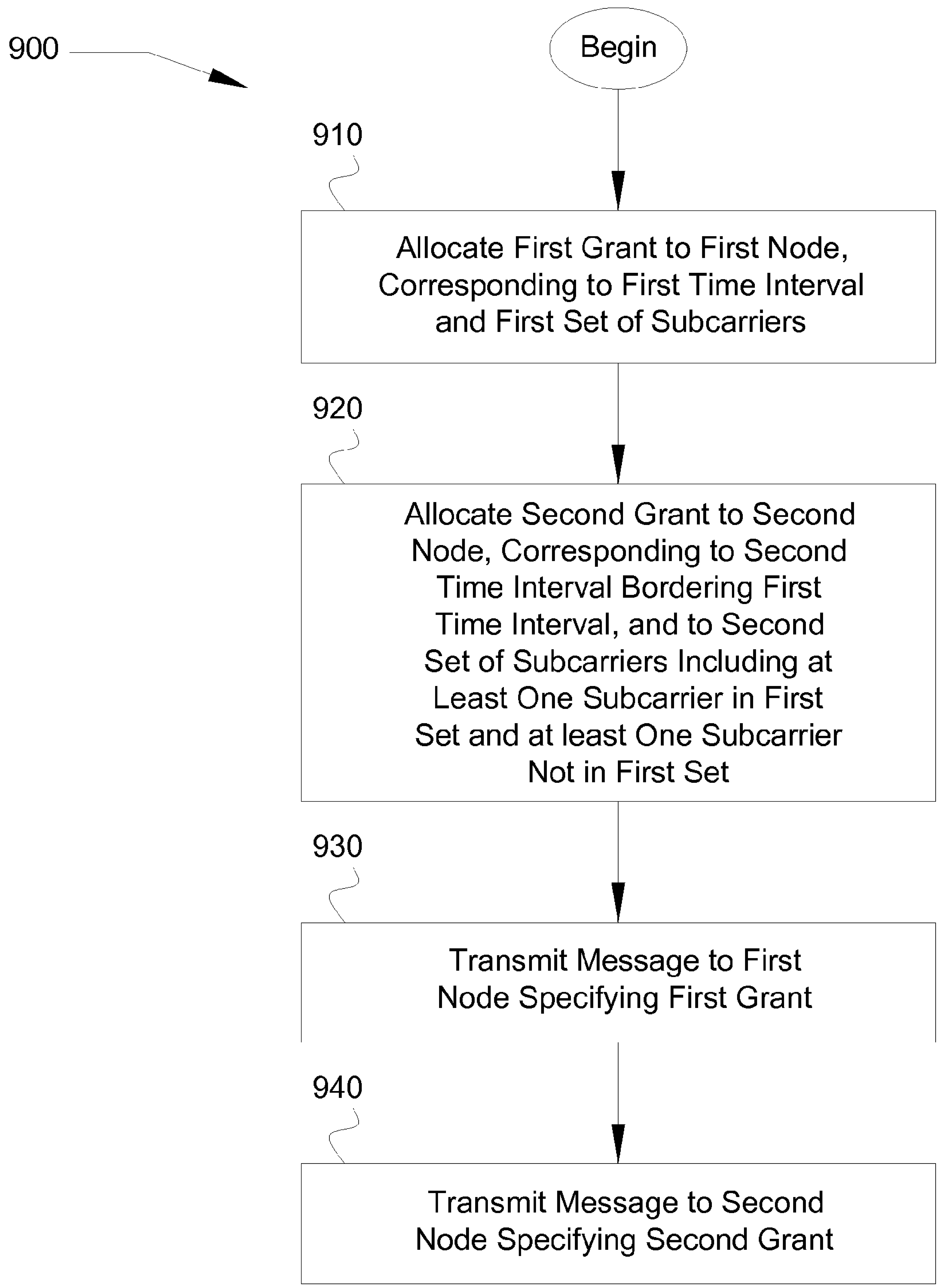
900
Begin
910
Allocate First Grant to First Node, Corresponding to First Time Interval and First Set of Subcarriers
920
Allocate Second Grant to Second Node, Corresponding to Second Time Interval Bordering First Time Interval, and to Second Set of Subcarriers Including at Least One Subcarrier in First Set and at least One Subcarrier Not in First Set
930
Transmit Message to First Node Specifying First Grant
940
Transmit Message to Second Node Specifying Second Grant

Figure 9

METHOD AND APPARATUS FOR ASYNCHRONOUS ORTHOGONAL FREQUENCY DIVISION MULTIPLE ACCESS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of application Ser. No. 13/041,662, filed Mar. 7, 2011, which claims priority under 35 U.S.C. §119(e) from the following provisional applications: Provisional Application Ser. No. 61/310,813 filed Mar. 5, 2010, the entirety of which is hereby incorporated by reference herein; Provisional Application Ser. No. 61/320,490, filed Apr. 2, 2010, the entirety of which is hereby incorporated by reference herein; Provisional Application Ser. No. 61/328,061, filed Apr. 26, 2010, the entirety of which is hereby incorporated by reference herein; and Provisional Application Ser. No. 61/371,284, filed Aug. 6, 2010, the entirety of which is hereby incorporated by reference herein.

FIELD

This disclosure is directed generally to communication systems. More particularly, some embodiments relate to a method and apparatus for asynchronous communication in an Orthogonal Frequency Division Multiple Access system.

BACKGROUND

Orthogonal Frequency Division Multiple Access (OFDMA) systems are prevalent today. Typically, in an OFDMA system, the signals of several different users (i.e., entities that wish to communicate over the communication system) will each be assigned one or more unique subcarriers. Each subcarrier is generated and transmitted in a manner that allows all of the subcarriers to be transmitted concurrently without interfering with one another. Therefore, independent information streams can be modulated onto each subcarrier whereby each such subcarrier can carry independent information from a transmitter to one or more receivers.

In one current OFDMA system described in the Multimedia over Coax Alliance (MoCA) industry standard, MoCA 2.0 network coordinators (NCs) (sometimes referred to as network controllers) coordinate synchronous OFDMA transmissions for upstream reservation requests. That is, each participating/requesting network node is scheduled to simultaneously transmit a preamble of a respective message, followed by a payload of the corresponding message that is transmitted simultaneously. Each node transmits on its own set of subcarriers, with a set of subcarriers defining a logical subchannel.

MoCA may be implemented in the context of a hybrid fiber-coaxial (HFC) broadband network **150** shown in FIG. **1**A. HFC network **150** includes a fiber optic network **151** and a coaxial network **152**. The fiber optic network **151** includes a transport ring **153**, including a head-end node **154**, one or more distribution hubs **156** (shown as hubs **156***a* and **156***b* in this example), and a cable modem termination system (CMTS) **158** for connection to one or more fiber optic nodes **160** (shown as fiber optic nodes **160***a* and **160***b* in this example; sometimes referred to as optical nodes) that provide an interface between the fiber portion **151** and coaxial portion **152** of the network **150**. Each optical node **160** includes a receiver **161** and a transmitter **162** that provide communications in downstream and upstream directions, respectively, as denoted by arrows **163** and **164**. The downstream direction typically corresponds to point-to-multipoint (i.e., broadcast) communications, and the upstream direction typically corresponds to multipoint-to-point communications. Receiver **162***a* converts the downstream-directed optically modulated signal originating from the transport ring **153** to an electrical signal for distribution to customers **180** (e.g., homes **180**) in a network **170**, which may be a residential network. A trunk RF amplifier **172** and one or more line RF amplifiers **174** may be used to increase signal strength. Transmitter **161***a* provides upstream communications from customers **180** to the head-end **154** on a return path.

Referring to FIG. **1**B, in a known OFDMA transmission technique, time-frequency slots that are two-dimensional intervals in time-frequency space are granted to transmitters T**1** and T**2**, respectively, which may correspond to respective nodes of residential network **170**. T**1** is granted a first set of one or more logical subchannels **110***a*, and T**2** is granted a second set of one or more logical subchannels **110***b*, with T**1** granted more bandwidth in this example. Time intervals are granted on the basis of fixed time duration, which may correspond to a given number of symbols (e.g., 20 symbols). Two time intervals **120***a* and **120***b* of equal duration are shown in this example. The transmission schedule is synchronous in this example, and the time-frequency slots conform to a periodic grid.

Each data stream (e.g., packet) that is sent starts transmission at the same time so that the preambles of packets sent by respective transmitters are aligned in time. In this example, packets **132** and **142** are sent at the same time (i.e., at the start of time interval **120***a*) so that their respective preambles **133** and **143** are aligned in time. However, packets may have different lengths, e.g., due to differing lengths of respective payloads **134** and **144**. Therefore, if a shorter packet (e.g., packet **132**) is sent on one set of subchannels (e.g., subchannels **110***a*), and a longer packet (e.g., packet **142**) is sent on another set of subchannels (e.g., subchannels **110***b*), the subchannels on which the shorter packet was sent will be padded or idle, waiting for the completion of the transmission of the longer packet, as shown by idle interval **122**. Additional packets may be sent in the next time interval **120***b*.

In particular, in a network where all upstream traffic is destined for a network coordinator (NC), the beginning and end of various packet transmissions may not align precisely. This misalignment may be due by different nodes transmitting packets of various lengths (e.g., from 64 to 1518 bytes each). Alternatively, this misalignment may be due to different nodes transmitting over separate subchannels with differing bit loadings and subchannel widths. For example, a first node may be required to transmit its packets over subchannels corresponding to narrower bandwidth than a second node. The first node may use a lower-order bit loading than the second node in order to improve the fidelity of the transmission. Since the system is constrained to synchronous OFDMA, a node with a short packet (destined for the NC) might have to wait for another node to finish transmitting a long packet (also destined for the NC) before the two nodes could synchronously transmit respective their preambles and new payloads, limiting flexibility and efficiency.

SUMMARY

In some embodiments, a method of transmitting orthogonal frequency division multiple access signals includes transmitting, at a first transmitter of a network, a first stream of data having a first number of symbols over a first time interval using a first set of one or more Orthogonal Frequency Division Multiple Access (OFDMA) subcarriers. At a second transmitter of the network, a second stream of data is transmitted having a second number of symbols over a second time interval, different in duration than the first time interval and overlapping the first time interval. The second burst of data is transmitted using a second set of one or more OFDMA subcarriers. The first time interval and first set of subcarriers define a first time-frequency grant, the second time interval and second set of subcarriers define a second time-frequency grant, and the first and second time-frequency grants are granted by a network coordinator node of the network.

In some embodiments, a method of transmitting orthogonal frequency division multiple access signals includes transmitting, at a first transmitter of a network, a first stream of data over a first time interval using a first set of one or more Orthogonal Frequency Division Multiple Access subcarriers. At a second transmitter of the network, a second stream of data is transmitted over a second time interval using a second set of one or more OFDMA subcarriers. The first time interval and first set of subcarriers define a first time-frequency grant, the second time interval and second set of subcarriers define a second time-frequency grant, and the first and second time-frequency grants are granted by a network coordinator node of the network.

In some embodiments, a method of scheduling transmission of orthogonal frequency division multiple access signals is performed at a network coordinator node of a network. The method includes allocating a first time-frequency grant to a first network node of the network. The first time-frequency grant corresponds to a first time interval and a first set of one or more orthogonal frequency division multiple access subcarriers. A second time-frequency grant is allocated to a second network node of the network. The second time-frequency grant corresponds to a second time interval, different in duration than the first time interval and overlapping the first time interval, and to a second set of one or more OFDMA subcarriers. A first message is transmitted to the first network node specifying the first time-frequency grant, and a second message is transmitted to the second network node specifying the second time-frequency grant.

In some embodiments, a method of scheduling transmission of orthogonal frequency division multiple access signals is performed at a network coordinator node of a network. The method includes allocating a first time-frequency grant to a first network node of the network. The first time-frequency grant corresponds to a first time interval and a first set of one or more orthogonal frequency division multiple access subcarriers. A second time-frequency grant is allocated to a second network node of the network. The second time-frequency grant corresponds to a second time interval, bordering the first time interval, and to a second set of one or more OFDMA subcarriers. The second set includes at least one subcarrier in the first set and at least one subcarrier not in the first set. A first message is transmitted to the first network node specifying the first time-frequency grant, and a second message is transmitted to the second network node specifying the second time-frequency grant.

In some embodiments, an apparatus (which may include a microchip) includes a processor, a computer readable storage medium, a buffer, a transmitter, a receiver, a timer, and a bus that is configured to provide communication between other apparatus components. Within a chip corresponding to a network node on a network, the processor functions to implement the transmission schedule for that node. Instructions stored tangibly on the storage medium may cause the processor **410** to effectuate transmission in accordance with the methods of transmitting orthogonal frequency division multiple access signals described above. Schedule orders received from a network coordinator (NC) via the receiver may be stored in the buffer. Based on the timer and the schedule received from the NC, the processor may cause the transmitter to initiate a data burst (transmit a stream of data).

In some embodiments, an apparatus (which may include a microchip) forming a network coordinator (NC) node on a network includes a processor, a computer readable storage medium, a transmitter, a receiver, a timer, and a bus that is configured to provide communication between other apparatus components. Within a chip corresponding to the NC, the processor functions to determine a time-frequency grant schedule for various recipient nodes and transmit the schedule to the recipient nodes. Instructions stored tangibly on the storage medium may cause the processor **410** to effectuate transmission of messages indicating the grants in accordance with the methods of scheduling transmission of orthogonal frequency division multiple access signals described above. The NC node is configured to coordinate asynchronous transmissions for upstream reservation requests of the first and second recipient network nodes received at the receiver.

BRIEF DESCRIPTION OF THE DRAWINGS

The following will be apparent from elements of the figures, which are provided for illustrative purposes and are not necessarily to scale.

FIG. **1**A is a network diagram of a known hybrid fiber/coaxial (HFC) broadband network topology.

FIG. **1**B is an illustration of a known Orthogonal Frequency Division Multiple Access transmission technique.

FIG. **2** is a block diagram of a communication system.

FIG. **3** is a block diagram of a network node in accordance with the communication system illustrated in FIG. **2**.

FIG. **4** is a block diagram of a hardware chip-level implementation of a network node in accordance with the communication system illustrated in FIG. **2**.

FIGS. **5**A-B are illustrations of OFDMA transmission in accordance with some embodiments.

FIG. **6** is a flow diagram in accordance with some embodiments.

FIG. **7** is a flow diagram in accordance with some embodiments.

FIG. **8** is a flow diagram in accordance with some embodiments.

FIG. **9** is a flow diagram in accordance with some embodiments.

DETAILED DESCRIPTION

This description of the exemplary embodiments is intended to be read in connection with the accompanying drawings, which are to be considered part of the entire written description.

Various embodiments of the present disclosure provide additional flexibility and efficiency relative to known synchronous OFDMA techniques by providing asynchronous OFDMA communication functionality.

FIG. **2** illustrates one example of a communication system **200** (network **200**) including a plurality of network nodes **210***a-g* (collectively referred to as "network nodes **210**") each configured to communicate with other nodes through a communication medium **202**, which may be channel **202**. Examples of the communication medium **202** include, but are not limited to, coaxial cable, fiber optic cable, a wireless transmission medium, an Ethernet connection, or the like. It is understood by those known in the art that the term "network medium" is the same as "communication medium." In one embodiment, communication medium **202** is a coaxial cable network.

Network nodes **210** may be devices of a home entertainment system such as, for example, set top boxes (STBs), televisions (TVs), computers, Digital Versatile Disc (DVD) or Blu-ray players/recorders, gaming consoles, or the like, coupled to each other via communication medium **202**. Various embodiments may be implemented on or using any such network node **210**.

In some embodiments, communication system **200** may be a Multimedia over Coax Alliance network. The MoCA architecture dynamically assigns a network node **210** as a network controller/network coordinator (NC) in order to optimize performance. Any network node **210** may be the NC, as is understood by one of ordinary skill in the art; for the sake of this example, assume network node **210***a* is an NC. Only a device in the NC **210***a* role is able to schedule traffic for all other nodes **210***b-g* in the network and form a full mesh network architecture between any device and its peers.

Embodiments of the present disclosure may be implemented in a MoCA network but are not limited to MoCA, which is a particular industry standard protocol. Rather, embodiments are applicable in a variety of access contexts.

Referring to FIG. **3**, each of the network nodes **210** may include a physical interface **302** including a transmitter **304** and a receiver **306**, which are in signal communication with a processor **308** through a data bus **310**. The transmitter **304** may include a modulator **312** for modulating data according to a quadrature amplitude modulation (QAM) scheme, e.g., 8-QAM, 16-QAM, 32-QAM, 64-QAM, 128-QAM, or 256-QAM, or another modulation scheme. The transmitter **304** may also include a digital-to-analog converter (DAC) **314** for transmitting modulated signals to other network nodes **300** through the communication medium **202**.

Receiver **306** may include an analog-to-digital converter (ADC) **316** for converting an analog modulated signal received from another network node **210** into a digital signal. Receiver **306** may also include an automatic gain control (AGC) circuit **318** for adjusting the gain of the receiver **306** to properly receive the incoming signal and a demodulator **320** for demodulating the received signal. One of ordinary skill in the art will understand that the network nodes **210** may include additional circuitry and functional elements not described herein.

Processor **308** may be any central processing unit (CPU), microprocessor, micro-controller, or computational device or circuit for executing instructions. As shown in FIG. **3**, the processor **308** is in signal communication with a computer readable storage medium **322** through data bus **310**. The computer readable storage medium may include a random access memory (RAM) and/or a more persistent memory such as a read only memory (ROM). Examples of RAM include, but are not limited to, static random-access memory (SRAM), or dynamic random-access memory (DRAM). A ROM may be implemented as a programmable read-only memory (PROM), an erasable programmable read-only memory (EPROM), an electrically erasable programmable read-only memory (EEPROM), or the like as will be understood by one skilled in the art.

FIG. **4** is a block diagram of a hardware chip-level implementation of a network node in accordance with the communication system illustrated in FIG. **2**. FIG. **4** shows various components that may be included on a chip to implement functionality corresponding to a network node, which may be a network coordinator (NC) node or another node. A NC node may include similar or same hardware as other nodes and may be designated as a NC node dynamically. A processor **410** (which may be processor **308** of FIG. **3**), a buffer **420**, a data flow control logic **430**, a physical interface **440**, an external host interface, and a system resource module **460** may be configured to communicate via a system bus **470**. The processor **420** may include a storage unit **412**, which may be computer readable storage medium **322** of FIG. **3**. In some embodiments, the storage unit **412** may be separate from the processor **420**. The buffer **420**, which may be a shared memory, is coupled to the processor **410** and buffers scheduling instructions that may be received from a NC node to facilitate transmission according to a schedule at the node level. The data flow control logic **430** coupled to the physical interface **440** performs low level control functionality. Transmission from the node occurs at the physical layer represented by physical interface **440**. The physical interface may be the physical interface **302** of FIG. **3** and may be used for inter-node communications. An optional host interface may include an Ethernet bridge, e.g., for providing compatibility between Ethernet and MoCA. The system resources **460** includes a timer **462** for triggering transmission at scheduled times. A clock signal and a reset signal may be provided to a serializer/deserializer **480**, converts between serial and parallel data, and to a phase locked loop **490**, which may provide a baseband clock to the system resource module **460**.

The chip architecture shown in FIG. **4** may be used to implement various embodiments; other architectures may be used as well. Nodes may correspond to various types of devices on a network (e.g., a MoCA network or any broadband network like network **150** having a network coordinator node), including set top boxes, televisions, DVD or Blu-ray players or recorders, gaming consoles, computers (e.g., personal computers, desktop computers, notebook computers, handheld computers, or smart phones), and other devices with suitable hardware for communication on a network and processing instructions. Each network node **210** may be implemented using a separate chip **400**. In some embodiments, a node designated as the network coordinator (NC) node determines a schedule for allotting subcarriers or subchannels to various network nodes (each having a transmitter) in a multiple access context with greater flexibility and efficiency than is available in the prior art. The NC node distributes pertinent schedule information to respective nodes, e.g., using broadcast messages (in which case schedule information for all nodes may be sent to each node) or unicast messages (in which case node-specific schedule information may be sent). Schedule information may be sent via media access plan (MAP) messages. Within each chip **400** corresponding to a particular node, the processor **410** functions to implement the transmission schedule for that node. Instructions stored tangibly in storage **412** may cause the processor **410** to effectuate transmission at the physical interface **440** in accordance with processes **600** and **700** described below in the context of FIGS. **6-7** for recipient nodes and in in accordance with processes **800** and **900** described below in the context of FIGS. **8-9** for a NC node. Schedule instructions received at a recipient node from the NC node may be stored in buffer **420**. Based on the timer **462** and the schedule received from the NC node, the processor of a recipient node may cause the transmitter (represented by physical interface **440** in FIG. **4**; transmitter details are shown in FIG. **3**) to initiate a data burst (data stream).

In accordance with some embodiments, an asynchronous orthogonal frequency division multiple access scheme is used in which a NC schedules nodes to start their OFDMA transmissions at the next symbol boundary without waiting for other nodes to finish. For example, this allows, one node to transmit its preamble while another node is transmitting its payload (and vice versa), without requiring time alignment of the start of each preamble. Since each node uses a different set (subchannel) of subcarriers, the NC node can distinguish between communications associated with different nodes.

Therefore, in accordance with some embodiments, transmitting orthogonal frequency division multiple access signals includes transmitting a first stream of data from a first node of a network. In one such embodiment, the first stream includes a preamble and payload.

A second stream of data is also transmitted from a second node of the network. In one such embodiment, the second stream includes a preamble and payload. However, the second stream has a shorter total length than the first stream. That is, the total amount of time necessary to transmit the preamble and the payload is shorter for the second stream than for the first stream. Nonetheless, the transmission of the second stream starts at essentially the same time as the transmission of the first stream.

In addition, in accordance with some embodiments, a third stream of data is transmitted from the second node of the network. The third stream also includes a preamble and payload. The transmission of the third stream begins at the end of the payload of the second stream and prior to the end of the transmission of the remainder of the payload of the first stream.

As in synchronous OFDMA, all subcarrier frequencies are preferably harmonically related to maintain orthogonality at the receiver (NC). Nonetheless, the NC node can still perform channel estimation and inverse equalization based on the received preamble symbol(s). The advantages of asynchronous OFDMA include: (1) relaxed constraints on the scheduler at the NC, (2) simplified assignment and distribution of subchannels, and (3) typically less waiting (idle time) on the channel. The tradeoff is that the system may be more complex due to the need to receive and process preambles and payloads simultaneously.

In another embodiment, an OFDMA receiver may not require preamble symbols. In this case, payload transmissions from one node may begin at a symbol boundary that is different from the symbol boundary at which other nodes begin their payload transmissions without the added complexity of receiving and processing preambles and payloads simultaneously. Similarly, payload transmissions from one node may end at a symbol boundary that is different from the symbol boundary at which other nodes end their payload transmissions.

Various embodiments may be used in full-mesh OFDMA networks (multipoint-to-multipoint) in which one or more receivers receive transmissions from one or more other transmitters.

FIGS. **5**A-B are illustrations of OFDMA transmission in accordance with some embodiments. FIG. **5**A shows allotment of frequency over time (i.e., allotment in time-frequency space) for transmitters T**1**, T**2**, T**3**, and T**4**. The transmitters may be allotted (granted) subchannels occupying different amounts of bandwidth. One or more subchannels may be assigned to each transmitter, with each subchannel comprising a set of one or more subcarriers that are adjacent in frequency or distributed (non-adjacent) in frequency. Adjacent subcarriers are associated with better channel coherence within subchannels, and distributed subcarriers are associated with better frequency diversity within subchannels. A mapping of subcarriers to subchannels may be predetermined at a head-end node and pre-distributed to various nodes via a downstream broadcast.

During time interval **510***a*, transmitters T**1** and T**2** are assigned grants **501** and **502**, respectively. Rather than requiring transmitter T**3** to adhere to the same timing allotment as transmitters T**1** and T**2**, embodiments allow T**3** to transmit bursts in grants **503** and **505** having respective intervals **520***a* and **520***b* that are shorter than interval **510***a*. Similarly, T**4** transmits bursts in grants **504** and **506** having time intervals **520***a* and **520***b*, respectively.

Embodiments provide increased flexibility and efficiency by transmitter T**3** to begin a new burst in grant **505** before a burst in grant **502** has completed (e.g., before transmission of the entirety of the payload of a packet transmitted in grant **502**). Providing a hybrid allotment capability ensures that advantageous characteristics of both long and short time allotments may be realized in the context of varying service needs and network conditions. Providing relatively long-duration grants (e.g., grants **501** and **502** in FIG. **5**A) typically offers the advantage of low overhead at the cost of high latency. Additionally, because a given amount of data transmitted over a longer interval (e.g., with more symbols) requires less bandwidth, increasing the burst time duration typically increases the number of transmitters needed. For the same given amount of data to be transmitted in a multiple access context, reducing burst length reduces latency and the number of transmitters needed but increases overhead (because more grants need to be scheduled, accounted for, and executed).

To make clear the latency reduction when decreasing the time duration of grants, consider the following example. Suppose fixed bursts of length 20 symbols are used, and suppose bursts in grants **501** and **502** are two such 20-symbol bursts. Then the physical layer (PHY) buffering latency (i.e., the time from when a report is received to the next schedulable transmission opportunity, or the time the scheduler must wait for the PHY in other words) is on average half of 20 symbols, i.e., 10 symbols. If the burst length is halved (and the burst frequency width is doubled) to 10 symbols, then PHY buffering latency will be 5 symbols, for an improvement of 5 symbols. In addition to the PHY buffering latency reduction, a PHY transmission duration latency reduction of 10 symbols is observed when reducing the burst length from 20 to 10 symbols. Then, the total PHY latency reduction is 5+10=15 symbols.

Thus, each regime (relatively long or short bursts) has its advantages and disadvantages. Formerly, multiple access implementations have been constrained to one regime or the other. Various embodiments allow the benefits of either regime to be enjoyed as shown in FIG. **5**A. In some embodiments, certain frequency ranges may be reserved for certain traffic classes. For example, frequency interval **530** may be reserved for residential access (e.g., consumer modems), and frequency interval **540** may be reserved for commercial service level agreements (SLAs). Long and short bursts may also be assigned for a given user based on different data characteristics and requirements, e.g., email (tolerant of high latency) and video (demanding low latency). Scheduling OFDMA transmissions asynchronously as in various embodiments, with flexible transmission start times, enables various objectives to be met in changing circumstances.

Asynchronous OFDMA also includes dynamic scheduling and allocation of time-frequency bursts in some embodiments. As shown in FIG. **5**B, various types of grants (having various time durations and frequency extents) may be scheduled and executed, e.g., based on real-time network and traffic conditions. Time-frequency grants may be configured in various ways and with time-frequency tiles of various shapes and sizes (hetereogeneous tiling). In its simplest form, a tile represents the usage by a transmitter of one or more subcarriers at various times corresponding to symbol slots. Thus, tiles may start and end (in the time dimension) at symbol boundaries. Some tiles may be conceptualized as rectangular in the sense of a uniform allotment of logical subchannels over a given time interval, with the understanding that subchannels may comprise distributed (non-adjacent) subcarriers, so a tile need not comprise a topologically connected region in time-frequency space. In the example of FIG. **5**B, nonrectangular tile **550** may be decomposed into multiple rectangular tiles. As opposed to homogeneous tiling dictated by conventional synchronous OFDMA techniques, asynchronous OFMDA in accordance with various embodiments allows transmitters to be allotted as many or as few subcarriers as appropriate, and for differing lengths of time.

Heterogeneity in the time duration of tiles was discussed above in the context of FIG. **5**A. FIG. **5**B illustrates heterogeneity in frequency as well, with tiles **560** and **562** having different frequency characteristics and not conforming to a periodic time-frequency grid as in prior art approaches. Tile **560** includes at least one subcarrier not included in tile **562**. By providing heterogeneity in time and frequency, embodiments facilitate the scheduling of a given amount of data in various ways. For example, if latency is at a premium or the network is not congested, additional subchannels may be included in a grant, and if bandwidth is scarce, fewer subchannels may be used in conjunction with a longer time interval. Because tiling is not constrained to a rectangular grid that is periodic in time and frequency, various scheduling methodologies may be used. For example, a scheduler at a network coordinator (NC) may optimally place low-latency bursts and then schedule latency-tolerant bursts to efficiently fill in any remaining gaps in time-frequency space with tiles that are appropriately dimensioned.

FIG. **6** is a flow diagram in accordance with some embodiments. After process **600** begins, at a first network node of a network (e.g., at a transmitter at the first network node), a first stream of data having a first number of symbols is transmitted (**610**) over a first time interval using a first set of one or more Orthogonal Frequency Division Multiple Access subcarriers. At a second network node of the network (e.g., at a transmitter at the second network node), a second stream of data is transmitted (**620**) having a second number of symbols over a second time interval, different in duration than the first time interval and overlapping the first time interval. The second burst of data is transmitted using a second set of one or more OFDMA subcarriers. The first time interval and first set of subcarriers define a first time-frequency grant, the second time interval and second set of subcarriers define a second time-frequency grant, and the first and second time-frequency grants are granted by a network coordinator node of the network. The first and second time intervals may have different start times, end times, or both. At the second network node, a third stream of data may be transmitted beginning at a symbol boundary succeeding the end of the second time interval. The end of the first time interval may be after the end of the second time interval, and the symbol boundary may be before the end of the first time interval. Thus, a data stream can begin transmission at a next symbol boundary without having to wait for other nodes to finish transmission of their respective streams as in conventional OFDMA approaches.

FIG. **7** is a flow diagram in accordance with some embodiments. After process **700** begins, at a first network node of a network (e.g., at a transmitter at the first network node), a first stream of data is transmitted (**710**) over a first time interval using a first set of one or more OFDMA subcarriers. At a second network node of the network (e.g., at a transmitter at the second network node), a second stream of data is transmitted (**720**) over a second time interval using a second set of one or more OFDMA subcarriers. The second set includes at least one subcarrier in the first set and at least one subcarrier not in the first set. The first time interval and first set of subcarriers define a first time-frequency grant, the second time interval and second set of subcarriers define a second time-frequency grant, and the first and second time-frequency grants are granted by a network coordinator node of the network. The first network node may be the same as the second network node, and the first and second time intervals may border one another, in which case a single transmitter transmits in adjacent time intervals using different frequency allotments.

Various combinations of overlapping time intervals and overlapping frequency subcarriers may be used, following the disclosure above regarding processes **600** and **700**, to achieve heterogeneous tiling in the time-frequency space.

FIG. **8** is a flow diagram in accordance with some embodiments. After process **800** begins, a first time-frequency grant is allocated (**810**) to a first network node of the network. The first time-frequency grant corresponds to a first time interval and a first set of one or more orthogonal frequency division multiple access subcarriers. A second time-frequency grant is allocated (**820**) to a second network node of the network. The second time-frequency grant corresponds to a second time interval, different in duration than the first time interval and overlapping the first time interval, and to a second set of one or more OFDMA subcarriers. A first message is transmitted (**830**) to the first network node specifying the first time-frequency grant, and a second message is transmitted (**840**) to the second network node specifying the second time-frequency grant.

FIG. **9** is a flow diagram in accordance with some embodiments. After process **900** begins, a first time-frequency grant is allocated (**910**) to a first network node of the network. The first time-frequency grant corresponds to a first time interval and a first set of one or more orthogonal frequency division multiple access subcarriers. A second time-frequency grant is allocated (**920**) to a second network node of the network. The second time-frequency grant corresponds to a second time interval, bordering the first time interval, and to a second set of one or more OFDMA subcarriers including at least one subcarrier in the first set and at least one subcarrier not in the first set. A first message is transmitted (**930**) to the first network node specifying the first time-frequency grant, and a second message is transmitted (**940**) to the second network node specifying the second time-frequency grant.

While various embodiments of the disclosed method and apparatus have been described above, it should be understood that they have been presented by way of example only, and should not limit the claimed invention. The claimed invention is not restricted to the particular example architectures or configurations disclosed. Rather, the desired features can be implemented using a variety of alternative architectures and configurations. Indeed, it will be apparent to one of skill in the art how alternative functional, logical or physical partitioning and configurations can be implemented to implement the desired features of the disclosed method and apparatus. Thus, the breadth and scope of the claimed invention should not be limited by any of the above-described exemplary embodiments.

Terms and phrases used in this document, and variations thereof, unless otherwise expressly stated, should be construed as open ended as opposed to limiting. As examples of the foregoing: the term "including" should be read as meaning "including, without limitation" or the like; the term "example" is used to provide examples of instances of the item in discussion, not an exhaustive or limiting list thereof; the terms "a" or "an" should be read as meaning "at least one," "one or more" or the like; and adjectives such as "conventional," "traditional," "normal," "standard," "known" and terms of similar meaning should not be construed as limiting the item described to a given time period or to an item available as of a given time, but instead should be read to encompass conventional, traditional, normal, or standard technologies that may be available or known now or at any time in the future. Likewise, where this document refers to technologies that would be apparent or known to one of ordinary skill in the art, such technologies encompass those apparent or known to the skilled artisan now or at any time in the future.

A group of items linked with the conjunction "and" should not be read as requiring that each and every one of those items be present in the grouping, but rather should be read as "and/or" unless expressly stated otherwise. Similarly, a group of items linked with the conjunction "or" should not be read as requiring mutual exclusivity among that group, but rather should also be read as "and/or" unless expressly stated otherwise. Furthermore, although items, elements or components of the disclosed method and apparatus may be described or claimed in the singular, the plural is contemplated to be within the scope thereof unless limitation to the singular is explicitly stated.

What is claimed is:

1. A method of transmitting asynchronous orthogonal frequency division multiple access signals over a Multimedia over Coax Alliance (MoCA) network, the method comprising:

transmitting, at a first network node of the MoCA network, a first stream of data having a first number of symbols over a first time interval using a first set of one or more orthogonal frequency division multiple access (OFDMA) subcarriers; and

transmitting, at a second network node of the MoCA network, a second stream of data having a second number of symbols over a second time interval different in duration than the first time interval and overlapping the first time interval, using a second set of one or more OFDMA subcarriers;

wherein the first time interval and first set of subcarriers define a first time-frequency grant, the second time interval and second set of subcarriers define a second time-frequency grant, the first and second time intervals end at different times, and the first and second time-frequency grants are granted to the first and second network nodes, respectively, by a network coordinator node of the MoCA network;

wherein the first time-frequency grant and second time-frequency grant are for upstream data transmissions; and

wherein the network coordinator node schedules upstream data transmissions by network nodes in the MoCA network.

2. The method of claim **1** wherein the first and second time intervals begin at different times.

3. The method of claim **1** wherein the first and second sets of subcarriers are reserved for data of first and second traffic classes, respectively.

4. The method of claim **3** wherein the first traffic class is residential traffic, and the second traffic class is commercial service level agreement (SLA) traffic.

5. The method of claim **1**, further including transmitting, at the second network node, a third stream of data beginning at a symbol boundary succeeding the end of the second time interval;

wherein the end of the first time interval is after the end of the second time interval, and the symbol boundary is before the end of the first time interval.

6. The method of claim **5**, wherein the first and second time intervals begin at the same time.

7. A method of transmitting asynchronous orthogonal frequency division multiple access signals over a Multimedia over Coax Alliance (MoCA) network, the method comprising:

transmitting, at a first network node of the MoCA network, a first stream of data over a first time interval using a first set of one or more orthogonal frequency division multiple access (OFDMA) subcarriers; and

transmitting, at a second network node of the MoCA network, a second stream of data over a second time interval using a second set of one or more OFDMA subcarriers including at least one subcarrier in the first set and at least one subcarrier not in the first set;

wherein the first time interval and first set of subcarriers define a first time-frequency grant, the second time interval and second set of subcarriers define a second time-frequency grant, the first and second time intervals end at different times, and the first and second time-frequency grants are granted to the first and second network nodes, respectively, by a network coordinator node of the MoCA network; and

wherein the first time-frequency grant and second time-frequency grant are for upstream data transmissions to the network coordinator; and

wherein the network coordinator node schedules upstream data transmissions by network nodes in the MoCA network.

8. The method of claim **7** wherein the first time interval borders the second time interval.

9. A method of scheduling transmission of asynchronous orthogonal frequency division multiple access signals over a Multimedia over Coax Alliance (MoCA) network, the method performed at a network coordinator node of the MoCA network, the method comprising:

allocating a first time-frequency grant to a first network node of the MoCA network, the first time-frequency grant corresponding to a first time interval and a first set of one or more orthogonal frequency division multiple access (OFDMA) subcarriers;

allocating a second time-frequency grant to a second network node of the MoCA network, the second time-frequency grant corresponding to a second time interval, different in duration than the first time interval and overlapping the first time interval, and a second set of one or more OFDMA subcarriers, wherein the first and second time intervals end at different times;

transmitting a first message to the first network node specifying the first time-frequency grant; and

transmitting a second message to the second network node specifying the second time-frequency grant;

wherein the first time-frequency grant and second time-frequency grant are for upstream data transmissions; and

wherein the network coordinator node schedules upstream data transmissions by network nodes in the MoCA network.

10. A method of scheduling transmission of asynchronous orthogonal frequency division multiple access signals over a Multimedia over Coax Alliance (MoCA) network, the method comprising:

allocating a first time-frequency grant to a first network node of the MoCA network, the first time-frequency grant corresponding to a first time interval and a first set of one or more orthogonal frequency division multiple access (OFDMA) subcarriers;

allocating a second time-frequency grant to a second network node of the MoCA network, the second time-frequency grant corresponding to a second time interval, bordering the first time interval, and a second set of one or more OFDMA subcarriers including at least one subcarrier in the first set and at least one subcarrier not in the first set, wherein the first and second time intervals end at different times;

transmitting a first message to the first network node specifying the first time-frequency grant; and

transmitting a second message to the second network node specifying the second time-frequency grant;

wherein the first and second time-frequency grants are granted to the first and second network nodes, respectively, by a network coordinator node of the MoCA network;

wherein the first time-frequency grant and second time-frequency grant are for upstream data transmissions; and

wherein the network coordinator node schedules upstream data transmissions by network nodes in the MoCA network.

11. An apparatus forming a network node on a Multimedia over Coax Alliance (MoCA) network, said apparatus comprising:

a computer processor;

a physical layer interface including a transmitter and a receiver, said physical layer interface configured to provide communication between said apparatus and at least one other network node on the network, said at least one other network node including a network coordinator (NC) node;

a buffer coupled to said processor, said buffer configured to store schedule orders received from said NC node;

a timer;

a bus configured to provide communication between said processor, said physical layer interface, said buffer, and said timer;

a computer readable storage medium having computer-executable instructions stored tangibly thereon, said instructions when executed causing said processor to transmit upstream, at a time based on the stored schedule orders and the timer, a first stream of data having a first number of symbols over a first time interval using a first set of one or more orthogonal frequency division multiple access (OFDMA) subcarriers;

wherein the first burst of data has a different number of symbols than a second burst of data that is transmitted upstream at one of the other network nodes over a second time interval different in duration than the first time interval and overlapping the first time interval, using a second set of one or more OFDMA subcarriers,

wherein the first and second time intervals end at different times; and

wherein the network coordinator node schedules upstream data transmissions by network nodes in the MoCA network, the upstream data transmissions including the first burst of data and the second burst of data.

12. The apparatus of claim **11** wherein the first and second time intervals begin at different times.

13. The apparatus of claim **11** implemented in a set top box configured to communicate over the network.

14. The apparatus of claim **11** implemented in a television configured to communicate over the network.

15. The apparatus of claim **11** implemented in a DVD or Blu-ray player or recorder.

16. The apparatus of claim **11** implemented in a gaming console.

17. The apparatus of claim **11** implemented in a computer configured to communicate over the network.

18. An apparatus forming a network node on a Multimedia over Coax Alliance (MoCA) network, said apparatus comprising:

a computer processor;

a physical layer interface including a transmitter and a receiver, said physical layer interface configured to provide communication between said apparatus and at least one other network node on the network, said at least one other network node including a network coordinator (NC) node;

a buffer coupled to said processor, said buffer configured to store schedule orders received from said NC node;

a timer;

a bus configured to provide communication between said processor, said physical layer interface, said buffer, and said timer;

a computer readable storage medium having computer-executable instructions stored tangibly thereon, said instructions when executed causing said processor to transmit upstream, at a time based on the stored schedule orders and the timer, a first stream of data over a first time interval using a first set of one or more orthogonal frequency division multiple access (OFDMA) subcarriers;

wherein at least one subcarrier in the first set is in a second set of one or more OFDMA subcarriers used for transmitting upstream a second stream of data at a second network node of the MoCA network over a second time interval, the first and second time intervals end at different times, and at least one subcarrier in the first set is not in the second set; and

wherein the NC node schedules upstream data transmissions by network nodes in the MoCA network, the upstream data transmissions including the first stream of data and the second stream of data.

19. The apparatus of claim **18** wherein the first time interval borders the second time interval.

20. An apparatus forming a network coordinator (NC) node on a Multimedia over Coax Alliance (MoCA) network, said apparatus comprising:

a computer processor;

a physical layer interface including a transmitter and a receiver, said physical layer interface configured to provide communication between the NC node, a first recipient network node on the MoCA network, and a second recipient network node on the network;

a bus configured to provide communication between said processor and said physical layer interface;

a computer readable storage medium having computer-executable instructions stored tangibly thereon, said instructions when executed causing said processor to:

transmit a first message to the first recipient network node, the first message allocating to the first recipient node a first time-frequency grant corresponding to a first time interval and a first set of one or more orthogonal frequency division multiple access (OFDMA) subcarriers;

transmit a second message to the second recipient node, the second message allocating to the second recipient node a second time-frequency grant corresponding to a second time interval, different in duration than the first time interval and overlapping the first time interval, and a second set of one or more OFDMA subcarriers;

wherein the NC node is configured to coordinate asynchronous transmissions for upstream reservation requests of the first and second recipient network nodes received at the receiver, and the first and second time intervals end at different times;

wherein the first time-frequency grant and second time-frequency grant are for upstream data transmissions; and

wherein the NC node schedules upstream data transmissions by network nodes in the MoCA network.

21. An apparatus forming a network coordinator (NC) node on a Multimedia over Coax Alliance (MoCA) network, said apparatus comprising:

a computer processor;

a physical layer interface including a transmitter and a receiver, said physical layer interface configured to provide communication between the NC node, a first recipient network node on the MoCA network, and a second recipient network node on the MoCA network;

a bus configured to provide communication between said processor and said physical layer interface;

a computer readable storage medium having computer-executable instructions stored tangibly thereon, said instructions when executed causing said processor to:

transmit a first message to the first recipient network node, the first message allocating to the first recipient node a first time-frequency grant corresponding to a first time interval and a first set of one or more orthogonal frequency division multiple access (OFDMA) subcarriers;

transmit a second message to the second recipient node, the second message allocating to the second recipient node a second time-frequency grant corresponding to a second time interval, bordering the first time interval, and a second set of one or more OFDMA subcarriers including at least one subcarrier in the first set and at least one subcarrier not in the first set:

wherein the NC node is configured to coordinate asynchronous transmissions for upstream reservation requests of the first and second recipient network nodes received at the receiver, and the first and second time intervals end at different times;

wherein the first time-frequency grant and second time-frequency grant are for upstream data transmissions; and

wherein the NC node schedules upstream data transmissions by network nodes in the MoCA network.

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