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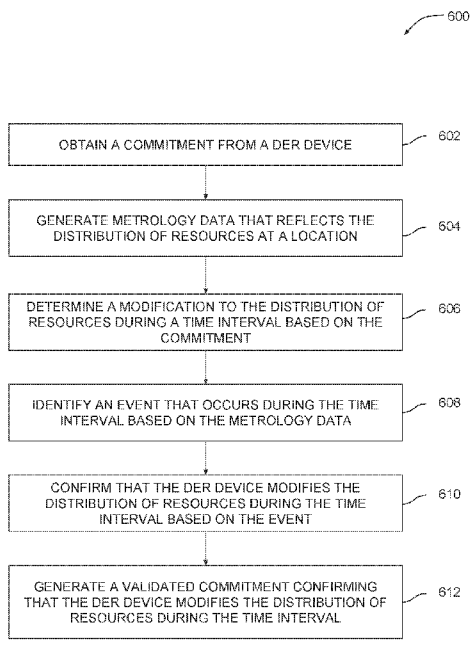


FIG. 6

(57) Abstract: A distributed energy resource (DER) device is coupled to a utility meter in a "behind-the-meter" configuration. The utility meter analyzes a commitment generated by the DER device to determine a specific operation performed by the DER device at a particular time. The utility meter analyzes metrology data to identify an "event" associated with the particular time and then attempts to map the identified event back to the DER device based on a library of events associated with different DER devices. The utility meter also attempts to map the identified event to the specific operation set forth in the commitment. If the utility meter can successfully map the identified event to both the DER device and to the specific operation set forth in the commitment, then the utility meter generates a validated commitment. The validated commitment can be used to facilitate an energy market settlement process.

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## REAL-TIME VALIDATION OF DISTRIBUTED ENERGY RESOURCE DEVICE COMMITMENTS

### CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the priority benefit of United States provisional  
5 patent application titled, "Real-Time Validation of Distributed Energy Resource Device  
Commitments," filed on January 31, 2019 and having serial number 62/799,673 and  
claims the priority benefit of United States patent application titled, "Real-Time  
Validation of Distributed Energy Resource Device Commitments," filed on March 13,  
2019, and having serial number 16/352,761. The subject matter of these related  
10 applications is hereby incorporated herein by reference.

### BACKGROUND

#### **Field of the Various Embodiments**

[0002] Embodiments of the present invention relate generally to utility networks  
and utility distribution infrastructures and, more specifically, to real-time validation of  
15 distributed energy resource device commitments.

#### **Description of the Related Art**

[0003] In conventional utility networks and utility distribution infrastructures, one or  
more utility providers generate resources that are distributed to one or more  
downstream resource consumers. For example, a nuclear power plant could  
20 generate electricity that is then distributed to various electricity consumers within a  
city. A given downstream resource consumer usually has a utility meter that monitors  
various characteristics associated with the distribution and/or consumption of  
resources. For example, a residence could have an electricity meter that monitors the  
rate at which the residence consumes electricity, the total amount of electricity  
25 distributed to the residence over a particular period of time, and so forth.

[0004] In more modern utility networks and utility distribution infrastructures, the  
downstream resource consumers sometimes have distributed energy resource (DER)  
devices that are configured to help distribute, generate, and/or store resources. One  
example of a DER device is a smart thermostat that, under specific circumstances,  
30 limits the amount of electricity being consumed by a consumer. Another example of a  
DER device is a solar power system that generates solar-based electricity for  
consumption by one or more consumers and/or for distribution onto a utility

distribution infrastructure. Yet another example of a DER device is a home battery system that stores electricity that can be subsequently consumed during periods of peak electricity demand. As a general matter, DER devices are deployed to reduce costs and to improve the efficiency with which resources can be distributed to

5 consumers.

**[0005]** In certain situations, a consumer can configure a given DER device to participate in one or more energy markets in order to earn financial incentives. For example, a consumer could configure a smart thermostat to participate in a demand-response program offered by a utility provider in exchange for a rebate or other form of compensation. As part of such a program, the consumer could configure the smart thermostat to turn off climate control at the residence of the consumer whenever the utility provider instructs the smart thermostat to do so, and the consumer would be compensated for participating in the program. Among other things, these types of arrangements enable utility providers to limit how much electricity is consumed during

10 periods of peak electricity demand.

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**[0006]** When a DER device participates in an energy market, the DER device is usually configured to operate in accordance with the terms of a contract. For example, a smart thermostat could be configured to operate in accordance with a contract that specifies the particular circumstances under which a utility provider can cause the smart thermostat to turn off or turn off climate control. The owners of such contracts can be utility providers, but, more typically, the contract owners are third-party vendors that manage the participation of DER devices in various energy markets on behalf of the utility providers.

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**[0007]** Contracts that manage the participation of DER devices in energy markets can specify a wide variety of different operations that participating DER devices need to perform. One requirement found in some contracts is that a participating DER device should generate "commitments" that indicate the specific actions the DER device implemented to fulfill various terms of the relevant contract. For example, a smart thermostat could generate a commitment indicating that the smart thermostat turned off climate control at the residence of a given consumer when instructed to do so by the relevant utility provider. Upon receiving a commitment, the contract owner analyzes the commitment to confirm that the terms of the contract have been met and thereby validate the commitment. The contract owner then compensates the

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consumer for participation in the energy market. The process of validating commitments and compensating consumers is referred to as the “settlement” process.

**[0008]** One drawback of the above approach is that the settlement process can take three months or more to complete. Consequently, consumers have to wait for extended periods of time to receive compensation when participating in energy market programs. These lengthy wait times can dissuade consumers from participating in energy market programs. If fewer consumers participate in energy market programs, then utility providers may have greater difficulty providing resources to consumers efficiently and at reduced cost.

**[0009]** As the foregoing illustrates, what is needed in the art are more effective ways to validate DER device commitments.

### **SUMMARY**

**[0010]** Some embodiments include a computer-implemented method for validating distributed resource device commitments, including determining that a first commitment received from a first distributed resource device indicates that the first distributed resource device modified how much of a resource was consumed at a first location during a first time interval, generating first metrology data that indicates how much of the resource was consumed at the first location during the first time interval, and validating the first commitment based on the first metrology data associated with the first location.

**[0011]** One technological advantage of the disclosed approach relative to the prior art is that commitments reported by distributed resource devices are validated automatically by the utility meter, which enables the settlement process to be performed much faster relative to conventional approaches.

### **BRIEF DESCRIPTION OF THE DRAWINGS**

**[0012]** So that the manner in which the above recited features of the various embodiments can be understood in detail, a more particular description of the inventive concepts, briefly summarized above, may be had by reference to various embodiments, some of which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate only typical embodiments of the

inventive concepts and are therefore not to be considered limiting of scope in any way, and that there are other equally effective embodiments.

**[0013]** Figure 1 illustrates a network system configured to implement one or more aspects of the present embodiments;

5 **[0014]** Figure 2 illustrates an exemplary behind-the-meter configuration, according to various embodiments;

**[0015]** Figure 3 is a more detailed illustration of the node of Figure 2, according to various embodiments;

10 **[0016]** Figure 4 is a more detailed illustration of the validation application of Figure 3, according to various embodiments;

**[0017]** Figure 5 is a graph of metrology data that is processed by the node of Figure 2 when validating a commitment, according to various embodiments; and

**[0018]** Figure 6 is a flow diagram of method steps for validating DER device commitments, according to various embodiments.

15 **DETAILED DESCRIPTION**

**[0019]** In the following description, numerous specific details are set forth to provide a more thorough understanding of the various embodiments. However, it will be apparent to one of skilled in the art that the inventive concepts may be practiced without one or more of these specific details.

20 **[0020]** As noted above, DER devices can be configured to participate in energy markets in order to earn financial incentives for a consumer. To participate in a given energy market, the consumer or a third party configures the given DER device to operate in accordance with a contract that at least partially defines the operation of the DER device. When the DER device performs various operations in accordance  
25 with the contract, the DER device also generates a “commitment” indicating the specific actions the DER device performs to fulfil the terms of the contract. A contract holder, such as a utility provider or a third-party intermediary, then validates the commitment and compensates the consumer via a process that is referred to as “settlement.”

**[0021]** One drawback associated with a conventional settlement process is that validating commitments generally takes a long time, sometimes in excess of three months. For example, suppose a given DER device participates in an energy market and reports commitments to a contract holder to initiate the settlement process. To  
5 validate a given commitment, an analyst associated with the contract holder would first have to analyze the commitment to identify the particular operations performed by the DER device. The analyst would then have to analyze a contract associated with the energy market to determine whether those operations meet the terms of the contract. The analyst would also have to access utility meter data associated with the  
10 location where the DER device resides in order to verify that the DER device did, indeed, perform the reported operations. Specifically, the analyst would have to analyze the meter data during a time interval where the reported operations are supposed to have occurred, and then determine whether the meter data supports the occurrence of these operations. Depending on the availability of data, these analyses  
15 are carried out at varying levels of aggregation and accuracy.

**[0022]** The steps described above are manually performed by the analyst and can therefore take a long time. Further, contract holders are oftentimes backlogged with commitments and therefore cannot begin the settlement process immediately. These various delays ultimately cause the consumer to have to wait to be compensated for  
20 participating in the energy market. Consumers usually do not appreciate having to wait for compensation. As such, when the settlement process takes a long time, consumers may find participating in energy markets less desirable. Energy markets help improve the efficiency with which resources can be distributed. When fewer consumers participate in energy markets, utility providers can have difficulty providing  
25 consumers with resources efficiently and/or at low cost.

**[0023]** To address these issues, embodiments of the invention include a smart utility meter that validates commitments generated by DER devices coupled behind the smart utility meter. The DER devices reside in a location where the utility meter monitors the distribution of resources. The DER devices can modify the distribution,  
30 generation, and/or storage of resources at the location in accordance with, at least to some degree, a contract associated with an energy market. When a given DER device operates in accordance with a given contract, the DER device reports a

commitment to the smart utility meter indicating the specific operations the DER device performs to fulfill the terms of the contract.

**[0024]** The utility meter analyzes the commitment to determine a time interval when the reported operations were to occur. The utility meter then analyzes meter data associated with the distribution of resources at the location to identify any events associated with the time interval. Upon identifying an event, the utility meter can map the event to the DER device based on a library of events corresponding to different DER devices. The utility meter can also map the event to the reported operation. If the utility meter successfully maps the event to both the DER device and the reported operations, then the occurrence of the operations is confirmed and the DER device generates a validated commitment. The validated commitment can be transmitted to relevant parties in order to expedite the settlement process.

**[0025]** One technological advantage of the disclosed approach relative to the prior art is that commitments reported by DER devices are validated automatically by the utility meter, which enables the settlement process to be performed much faster relative to conventional approaches. Accordingly, consumers can be compensated for participating in energy markets much faster than the three-month or longer periods typically associated with conventional settlement processes. This technological advantage represents at least one technological advancement relative to prior art approaches.

### System Overview

**[0026]** Figure 1 illustrates a network system configured to implement one or more aspects of the present embodiments. As shown, network system 100 includes a field area network (FAN) 110, a wide area network (WAN) backhaul 120, and a control center 130. FAN 110 is coupled to control center 130 via WAN backhaul 120. Control center 130 is configured to coordinate the operation of FAN 110.

**[0027]** FAN 110 includes personal area network (PANs) A, B, and C. PANs A and B are organized according to a mesh network topology, while PAN C is organized according to a star network topology. Each of PANs A, B, and C includes at least one border router node 112 and one or more mains powered device (MPD) nodes 114. PANs B and C further include one or more battery powered device (BPD) nodes 116.

**[0028]** MPD nodes 114 draw power from an external power source, such as mains electricity or a power grid. MPD nodes 114 typically operate on a continuous basis without powering down for extended periods of time. BPD nodes 116 draw power from an internal power source, such as a battery. BPD nodes 116 typically operate  
5 intermittently and power down for extended periods of time in order to conserve battery power. MPD nodes 114 and BPD nodes 116 are configured to gather sensor data, process the sensor data, and communicate data processing results and other information to control center 130. Border router nodes 112 operate as access points to provide MPD nodes 114 and BPD nodes 116 with access to control center 130.

**[0029]** Any of border router nodes 112, MPD nodes 114, and BPD nodes 116 are configured to communicate directly with one or more adjacent nodes via bi-directional communication links. The communication links may be wired or wireless links, although in practice, adjacent nodes of a given PAN exchange data with one another by transmitting data packets via wireless radio frequency (RF) communications. The  
15 various node types are configured to perform a technique known in the art as “channel hopping” in order to periodically receive data packets on varying channels. As known in the art, a “channel” may correspond to a particular range of frequencies. In one embodiment, a node may compute a current receive channel by evaluating a Jenkins hash function based on a total number of channels, the media access control  
20 (MAC) address of the node, and other information associated with the node.

**[0030]** Each node within a given PAN may implement a discovery protocol to identify one or more adjacent nodes or “neighbors.” A node that has identified an adjacent, neighboring node may establish a bi-directional communication link with the neighboring node. Each neighboring node may update a respective neighbor table to  
25 include information concerning the other node, including the MAC address of the other node as well as a received signal strength indication (RSSI) of the communication link established with that node.

**[0031]** Nodes may compute the channel hopping sequences of adjacent nodes to facilitate the successful transmission of data packets to those nodes. In embodiments  
30 where nodes implement the Jenkins hash function, a node computes a current receive channel of an adjacent node using the total number of channels, the MAC address of the adjacent node, and a time slot number assigned to a current time slot of the adjacent node.



**[0032]** Any of the nodes discussed above may operate as a source node, an intermediate node, or a destination node for the transmission of data packets. A given source node may generate a data packet and then transmit the data packet to a destination node via any number of intermediate nodes (in mesh network topologies).

5 The data packet may indicate a destination for the packet and/or a particular sequence of intermediate nodes to traverse in order to reach the destination node. In one embodiment, each intermediate node may include a forwarding database indicating various network routes and cost metrics associated with each route.

**[0033]** Nodes may transmit data packets across a given PAN and across WAN backhaul 120 to control center 130. Similarly, control center 130 may transmit data packets across WAN backhaul 120 and across any given PAN to a particular node included therein. As a general matter, numerous routes may exist which traverse any of PANs A, B, and C and include any number of intermediate nodes, thereby allowing any given node or other component within network system 100 to communicate with  
15 any other node or component included therein.

**[0034]** Control center 120 includes one or more server machines (not shown) configured to operate as sources for, or destinations of, data packets that traverse within network system 100. The server machines may query nodes within network system 100 to obtain various data, including raw or processed sensor data, power consumption data, node/network throughput data, status information, and so forth.  
20 The server machines may also transmit commands and/or program instructions to any node within network system 100 to cause those nodes to perform various operations. In one embodiment, each server machine is a computing device configured to execute, via a processor, a software application stored in a memory to  
25 perform various network management operations.

**[0035]** Nodes may likewise include computing device hardware configured to perform processing operations and execute program code. Each node may further include various analog-to-digital and digital-to-analog converters, digital signal processors (DSPs), harmonic oscillators, transceivers, and any other components  
30 generally associated with RF-based communication hardware.

**[0036]** Any of the nodes discussed above can be configured as a smart utility meter and be coupled to a utility line in order to monitor the distribution of resources

at a particular location via the utility line. For example, an MPD node 114 could be configured as a smart electric meter and be coupled to a power line in order to monitor the distribution of electricity at a residence via the power line. A given node that is configured as a smart utility meter generates real-time metrology data  
5 quantifying the distribution of resources at the location where the given node resides. The given node then periodically reports this metrology data to control center 130 via FAN 110.

**[0037]** A given node that is configured as a smart utility meter can be coupled to, and configured to interoperate with, one or more DER devices in a “behind-the-meter”  
10 configuration. As referred to herein, a behind-the-meter or BTM configuration generally includes a node that is coupled to a utility line and one or more DER devices that are coupled to the utility line downstream of the node. The node monitors the distribution of resources via the utility line. The DER devices modify the distribution of resources via the utility line in a detectable manner. An exemplary  
15 behind-the-meter configuration is described in greater detail below in conjunction with Figure 2.

### **Exemplary Behind-the-Meter Configuration**

**[0038]** Figure 2 illustrates an exemplary behind-the-meter (BTM) configuration, according to various embodiments. As shown, BTM configuration 200 includes DER  
20 devices 210(0) through 210(N), a node 220, and utility line 230. DER devices 210 are coupled to node 220. DER devices 210 and node 220 are coupled to a utility line 230. In one embodiment, DER devices 210 may be coupled indirectly to utility line 230 via node 220. In another embodiment, DER devices 210 may be connected directly to utility line 230.

**[0039]** Utility line 230 is configured to distribute resources to a given location where BTM configuration 200 is deployed. For example, utility line 230 could be a power line that distributes electricity to a residence. Node 220 is configured as a smart utility meter that monitors the distribution of resources via utility line 230 to generate metrology data 222. For example, node 220 could be a smart electric meter  
30 configured to generate metrology data that reflects the distribution of electricity via utility line 230. Node 220 may be any of the node types discussed above in conjunction with Figure 1. Metrology data 222 quantifies the distribution and/or consumption of resources at the location where node 220 is deployed. Metrology

data 222 may have any technically feasible resolution, although in practice metrology data 222 has sufficient resolution to identify relevant DER-oriented events (e.g., one-second resolution).

**[0040]** Each DER device 210 is configured to perform various operations to modify the distribution of resources via utility line 230. For example, DER device 210(0) could be a smart thermostat that limits the consumption of electricity via utility line 230 by modifying climate control settings. Alternatively, DER device 210(0) could be a solar power system configured to generate electricity and distribute at least a portion of that electricity onto utility line 230. DER device 210(0) could also be a home battery system configured to draw electricity from utility line 230 for storage.

**[0041]** A given DER device 210 can modify the distribution of resources based on the terms of a contract associated with an energy market. In so doing, the given DER device 210 may generate one or more commitments 212 that indicate the specific operation(s) the DER device 210 performs over one or more time intervals to fulfill the terms of the corresponding contract. As is shown, DER devices 210(0) through 210(N) generate commitments 212(0) through 212(N) and then transmit these commitments to node 220.

**[0042]** Node 220 is configured to perform a real-time validation of commitments 212 based on metrology data 222. Node 220 validates commitments 212 to confirm that DER devices 210 operate in accordance with any associated energy market contracts. As is shown, node 220 generates validated commitments 224 based on commitments 212(0) through 212(N) and metrology data 222. Node 220 performs various operations to validate a given commitment 224, as described in greater detail below in conjunction with Figures 3-6.

**[0043]** Node 220 transmits validated commitments 224 to control center 130 to facilitate various settlement processes associated with the energy market(s) in which DER devices 210 participate. Because node 220 has already confirmed that commitments 212 accurately reflect the various operations DER devices 210 perform to participate in the energy market(s), those settlement processes can be performed expeditiously and with minimal oversight. Accordingly, the real-time validation performed by node 220 can accelerate how quickly consumers are compensated for

participation in energy markets. Node 220 is described in greater detail below in conjunction with Figure 3.

### Node Hardware Components

**[0044]** Figure 3 is a more detailed illustration of the node of Figure 2, according to various embodiments. As shown, node 220 includes a computing device 300 coupled to a transceiver 340 and an oscillator 350. Computing device 300 coordinates the operations of node 220. Transceiver 340 is configured to transmit and receive data packets across network system 100 using a range of channels and power levels. Oscillator 350 provides one or more oscillation signals according to which the transmission and reception of data packets can be scheduled. Node 220 may be used to implement any of border router nodes 112, MPD nodes 114, and BPD nodes 116 of Figure 1.

**[0045]** Computing device 300 includes a processor 310, input/output (I/O) 320, and memory 330, coupled together. Processor 310 may include any hardware configured to process data and execute software applications. Processor 310 may include a real-time clock (RTC) (not shown) according to which processor 310 maintains an estimate of the current time. I/O devices 320 include devices configured to receive input, devices configured to provide output, and devices configured to both receive input and provide output. Memory 330 may be implemented by any technically feasible storage medium.

**[0046]** Memory 330 includes a validation application 332. Validation application 332 includes program code that, when executed by processor 310, analyzes one or more commitments 212 based on metrology data 222 to generate validated commitments 224. To validate a given commitment 212 associated with a given DER device 210, node 220 analyzes the commitment 212 to determine a specific operation the DER device 210 performs during a particular time interval. Node 220 then analyzes metrology data 222 to identify an "event" associated with that particular time interval. The event could be, for example, a change in resource distribution that exceeds a threshold during the time interval, among other possible events. Node 220 attempts to map the identified event back to the DER device 210 based on a library of events associated with different DER devices. In one embodiment, the library of events may include various signature patterns of activity that can be uniquely associated with specific DER devices. Node 220 also attempts to map the identified

event to the specific operation set forth in the commitment 212. If node 220 successfully maps the identified event to the DER device 210 and to the specific operation set forth in commitment 212, then node 220 generates a validated commitment 224 confirming that the DER device 210 is responsible for performing the specific operation. Validation application 332 transmits the validated commitment 224 to control center 230 to facilitate a settlement process associated with an energy market in which the DER device 210 participates. Validation application 332 is described in greater detail below in conjunction with Figure 4.

### Node Software Modules

**[0047]** Figure 4 is a more detailed illustration of the validation application of Figure 3, according to various embodiments. As shown, validation application 332 includes a distribution monitor 400, an event analyzer 410, and a commitment validator 420. These various software modules interoperate to generate a validated commitment 224 based on metrology data 222 and a commitment 212, as described in greater detail herein.

**[0048]** Distribution monitor 400 is coupled to utility line 230 and configured to measure the real-time distribution of resources via utility line 230 to generate metrology data 222. Metrology data 222 includes one or more different channels of data collected over any technically feasible time period and with any resolution. As previously mentioned, in practice, metrology data 222 has one-second resolution.

**[0049]** Event analyzer 410 analyzes metrology data 222 to generate a distribution event 402. Distribution event 402 indicates some type of fluctuation in the distribution of resources. For example, distribution event 402 could indicate that the distribution of resources fell beneath a threshold level during a particular time interval. Event analyzer 410 can be configured to detect any technically feasible type of distribution event based on metrology data 222. Distribution events are discussed in greater detail below in conjunction with Figure 5.

**[0050]** Event analyzer 410 queries event models 412 based on distribution event 402 to identify a particular event model 412 that corresponds to distribution event 402. A given event model 412 generally describes a time-varying pattern of resource distribution fluctuations that can be attributed to the operation of a DER device 210. In one embodiment, each event model 412 may indicate an electrical signature

associated with a specific type of DER device 210 when performing a specific operation, such as powering on, powering off, or changing state. For example, one event model 412 could specify a decrease in electricity consumption that has specific characteristics indicative of a smart thermostat deactivating an air conditioning unit.

5 Event models 412 can include Machine Learning models, parametric models, or any other technically feasible type of model that reflects time-varying behavior. Event models 412 are discussed in greater detail below in conjunction with Figure 5.

**[0051]** Once event analyzer 410 successfully maps distribution event 402 to an event model 412, event analyzer 410 generates device identifier (ID) 414 to identify  
10 the particular type of DER device 210 responsible for causing distribution event 402. Event analyzer 410 then transmits distribution event 410 and device ID 414 to commitment validator 420. In one embodiment, once event analyzer 410 maps the distribution event 402 to the event model 412, event analyzer 410 may then update the event model 412 to reflect one or more characteristics of distribution event 402.  
15 In doing so, event analyzer 410 may implement Machine Learning to modify one or more parameters associated with the event model 402. This approach allows event models 412 to remain up-to-date with changing operational characteristics of DER devices 210.

**[0052]** Commitment validator 420 analyzes commitment 212 to determine the  
20 particular DER device 210 responsible for generating commitment 212. Commitment validator 420 also determines the specific operations the DER device 210 performs to satisfy the terms of an energy market contract during the time interval when those specific operations are to have occurred. Commitment validator 420 then processes distribution event 402 to confirm that those specific operations did, indeed, occur  
25 during the specified time interval.

**[0053]** For example, suppose commitment 212 indicates that DER device 210(0) begins storing power in a home battery system at a first point in time. Commitment validator 420 could confirm the occurrence of this particular operation upon determining that event 402 indicates a characteristic increase in electrical loading at  
30 the first point in time. Commitment validator 420 also processes device ID 414 to verify the identity of the DER device 210 responsible for generating commitment 212. In particular, commitment validator 420 determines that commitment 212 and device

ID 414 are both associated with the same type of DER device 210 or the same instance of a DER device 210.

**[0054]** When commitment validator 420 successfully confirms that distribution event 402 and device ID 414 collectively indicate that the DER device 210 performs the operations set forth in commitment 212 during the specified time interval, commitment validator 420 then generates validated commitment 224. Via the above techniques, validated commitments 224 can be generated automatically and in real time. Validated commitments 224 can then be used to expedite a settlement process associated with an energy market.

**[0055]** Figure 5 is a graph of exemplary metrology data that is processed by the node of Figure 2 when validating a commitment, according to various embodiments. As shown, a graph 500 includes metrology data 502 plotted against a time axis 510 and a wattage axis 520. Metrology data 502 indicates a time-varying wattage associated with a location where node 220 is deployed. That wattage decreases at time  $T_0$ , increases at  $T_1$ , and then decreases again at time  $T_2$ .

**[0056]** In the example described herein, validation application 332 within node 220 could analyze metrology data 502 and parameterize the various fluctuations shown in order to identify these fluctuations with specific DER devices 210. For example, validation application 332 could identify the slight decrease in wattage at time  $T_0$  with DER device 210(0) powering off based on an event model 412 that characterizes the operation of DER device 210(0). In this manner, validation application 332 can determine signature patterns within metrology data 502 that uniquely identify specific DER devices 210 and/or specific operations performed by DER devices 210. The techniques described herein can also be implemented relative to any technically feasible metric other than wattage, including other electrical parameters and other parameters associated with resource distribution.

**[0057]** Referring generally to Figures 1-5, any of the techniques discussed herein can be performed by one or more separate elements of network system 1. In one embodiment, validation application 332 may be a distributed software application that executes partially on node 220 and partially in one or more other computing environments. For example, a first portion of validation application 332 could execute on node 220 to generate metrology data 222 and distribution events 402. A second

portion of validation application 332 could execute remotely in a cloud-based environment to generate validated commitments 224 based on distribution events 402 and commitments 212. The second portion of validation application 332 could also execute locally on a device that resides proximate to node 220, such as a local server or a home smart device. In either case, when the first portion of validation application 332 detects an event, the second portion of validation application 332 may retroactively analyze metrology data 222 in greater detail to validate one or more commitments 212.

**[0058]** In another embodiment, node 220 may execute a distributed ledger client in order to share validated commitments 224 with other nodes that also execute the distributed ledger client. For example, node 220 could execute a blockchain client to participate in a blockchain network. In so doing, node 220 could transmit validated commitments 224 to other nodes in a hierarchy of nodes that participate in the blockchain network.

**[0059]** Persons skilled in the art will recognize that the techniques described herein can be implemented to validate any technically feasible type of operation that is performed by any technically feasible type of device coupled to any technically feasible type of resource distribution infrastructure. For example, the disclosed techniques could be implemented to validate modifications made to the distribution of water by a device that is coupled (directly or indirectly) to a water main.

### **Automatically Validating DER Device Commitments**

**[0060]** Figure 6 is a flow diagram of method steps for validating a DER device commitment in real time, according to various embodiments. Although the method steps are described in conjunction with the systems of Figures 1-5, persons skilled in the art will understand that any system configured to perform the method steps in any order falls within the scope of the present invention.

**[0061]** As shown, a method 600 begins at step 602, where node 220 of Figure 1 obtains a commitment from a DER device. Node 220 is coupled to a utility line at a given location and configured to monitor the distribution of resources to the location via the utility line, in like fashion as shown in Figure 2. The DER device is coupled to node 220 in a BTM configuration and can modify the distribution of resources at the location. For example, the DER device could be configured to draw resources from



the utility line or distribute resources onto the utility line. The resources could be, for example, electricity, gas, water, or any other technically feasible type of resource.

**[0062]** At step 604, node 220 generates metrology data that reflects the distribution of resources via utility line 230. For example, the metrology data could indicate a kilowatt-hour measurement of electricity distributed to a residence. The metrology data may include one or more channels of real-time data having any technically feasible resolution, including one-second resolution (or less).

**[0063]** At step 606, node 220 determines a modification to the distribution of resources that occurs during a first time interval based on the commitment. The DER device generates the commitment upon performing various operations that modify the distribution of resources at the location. The DER device generally performs these operations in accordance with a contract associated with an energy market. For example, the DER device could be a solar power system that distributes at least a minimum amount of power onto the power grid.

**[0064]** At step 608, node 220 identifies a distribution event that occurs during the time interval based on the metrology data. As referred to herein, a distribution event refers to a measurable fluctuation in the distribution of resources at the location, such as, for example, a spike in resource consumption or production, among others. Node 220 can be configured to detect any technically feasible type of distribution event associated with any type of utility.

**[0065]** At step 610, node 220 confirms that the DER device modifies the distribution of resources during the time interval based on the event. In particular, node 220 maps the event to the DER device based on a library of event models that characterize different DER devices. In so doing, node 220 validates the authenticity of the DER device and can generate a device ID, such as device ID 414 of Figure 4. Node 220 also maps the event to the modification of resource distribution indicated in the commitment, thereby confirming that the DER device did, in fact, modify the distribution of resources as reported in the commitment.

**[0066]** At step 612, node 220 generates a validated commitment confirming that the DER device modifies the distribution of resources during the time interval. Node 220 may then transmit the validated commitment to control center 130 in order

expedite a settlement process associated with the energy market contract. The disclosed approach advantageously generates validated commitments automatically and with minimal oversight.

**[0067]** In sum, a distributed energy resource (DER) device is coupled to a utility meter in a “behind-the-meter” configuration. The utility meter analyzes a commitment generated by the DER device to determine a specific operation performed by the DER device at a particular time. The utility meter analyzes metrology data to identify an “event” associated with the particular time and then attempts to map the identified event back to the DER device based on a library of events associated with different DER devices. The utility meter also attempts to map the identified event to the specific operation set forth in the commitment. If the utility meter can successfully map the identified event to both the DER device and to the specific operation set forth in the commitment, then the utility meter generates a validated commitment. The validated commitment can be used to facilitate an energy market settlement process.

**[0068]** One technological advantage of the disclosed approach relative to the prior art is that commitments reported by DER devices are validated automatically by the utility meter, which enables the settlement process to be performed much faster relative to conventional approaches. Accordingly, consumers can be compensated for participating in energy markets much faster than the three-month or longer periods typically associated with conventional settlement processes. This technological advantage represents at least one technological advancement relative to prior art approaches.

**[0069]** 1. Some embodiments include a computer-implemented method for validating distributed resource device commitments, the method comprising determining that a first commitment received from a first distributed resource device indicates that the first distributed resource device modified how much of a resource was consumed at a first location during a first time interval, generating first metrology data that indicates how much of the resource was consumed at the first location during the first time interval, and validating the first commitment based on the first metrology data.

**[0070]** 2. The computer-implemented method of clause 1, wherein validating the first commitment comprises generating a first validated commitment confirming that

the first commitment indicates that the first distributed resource device modified how much of the resource was consumed at the first location during the first time interval.

**[0071]** 3. The computer-implemented method of any of clauses 1-2, further comprising generating a first distributed ledger transaction based on the first validated  
5 commitment, and transmitting the first distributed ledger transaction to one or more nodes included in a distributed ledger network.

**[0072]** 4. The computer-implemented method of any of clauses 1-3, wherein  
10 validating the first commitment comprises identifying a first event that occurs at the first location based on the first metrology data, and determining that the first event indicates that the first distributed resource device modified how much of the resource was consumed at the first location during the first time interval.

**[0073]** 5. The computer-implemented method of any of clauses 1-4, wherein  
15 determining that the first event indicates that the first distributed resource device modified how much of the resource was consumed at the first location during the first time interval comprises mapping the first event to a first event model included in a library of event models, wherein the first event model indicates at least one operational attribute of the first distributed resource device.

**[0074]** 6. The computer-implemented method of any of clauses 1-5, further  
20 comprising modifying the first event model based on the first event, wherein the first event model comprises a Machine Learning model.

**[0075]** 7. The computer-implemented method of any of clauses 1-6, wherein the  
first distributed resource device restricts resource consumption at the first location to modify how much of the resource was consumed at the first location.

**[0076]** 8. The computer-implemented method of any of clauses 1-7, wherein the  
25 first distributed resource device offsets resource consumption at the first location via generation of additional resources to modify how much of the resource was consumed at the first location.

**[0077]** 9. The computer-implemented method of any of clauses 1-8, wherein  
generating the first metrology data comprises measuring, in real time, one or more

electrical characteristics corresponding to an electrical load associated with the first location.

**[0078]** 10. The computer-implemented method of any of clauses 1-9, wherein identifying the first event comprises determining that at least one of the one or more electrical characteristics exceeds a threshold value.

**[0079]** 11. Some embodiments include a non-transitory computer-readable medium storing program instructions that, when executed by a processor, causes the processor to validate distributed energy resource (DER) device commitments by performing the steps of determining that a first commitment received from a first distributed resource device indicates that the first distributed resource device modified how much of a resource was consumed at a first location during a first time interval, generating first metrology data that indicates how much of the resource was consumed at the first location during the first time interval, and validating the first commitment based on the first metrology data.

**[0080]** 12. The non-transitory computer-readable medium of clause 11, wherein the step of validating the first commitment comprises generating a first validated commitment confirming that the first commitment indicates that the first distributed resource device modified how much of the resource was consumed at the first location during the first time interval.

**[0081]** 13. The non-transitory computer-readable medium of any of clauses 11-12, wherein the step of validating the first commitment comprises identifying a first event that occurs at the first location based on the first metrology data, and determining that the first event indicates that the first distributed resource device modified how much of the resource was consumed at the first location during the first time interval.

**[0082]** 14. The non-transitory computer-readable medium of any of clauses 11-13, wherein determining that the first event indicates that the first distributed resource device modified how much of the resource was consumed at the first location during the first time interval comprises mapping the first event to a first event model included in a library of event models, wherein the first event model indicates at least one operational attribute of the first distributed resource device.

**[0083]** 15. The computer-implemented method of any of clauses 11-14, wherein the first distributed resource device restricts resource consumption at the first location or generates additional resources at the location to modify how much of the resource was consumed at the first location.

5 **[0084]** 16. The computer-implemented method of any of clauses 11-15, wherein the first distributed resource device comprises a smart electric device, a smart water device, or a smart gas device.

**[0085]** 17. Some embodiments include a system, comprising a memory that stores a software application, and a processor that, when executing the software application,  
10 is configured to perform the steps of determining that a first commitment received from a first distributed resource device indicates that the first distributed resource device modified how much of a resource was consumed at a first location during a first time interval, and validating the first commitment based on first metrology data that indicates how much of the resource was consumed at the first location during the  
15 first time interval.

**[0086]** 18. The system of clause 17, wherein the processor resides within a smart utility meter that monitors resource consumption at the first location to generate the metrology data.

**[0087]** 19. The system of any of clauses 17-18, wherein the processor is further  
20 configured to perform the additional step of obtaining the first metrology data from a node that is coupled to a resource distribution infrastructure and monitors resource consumption at the first location to generate the metrology data.

**[0088]** 20. The system of any of clauses 17-19, wherein the processor validates  
25 the first commitment by identifying a first event that occurs at the first location based on the first metrology data, determining that the first event indicates that the first distributed resource device modified how much of the resource was consumed at the first location during the first time interval, and generating a validated commitment confirming that the first commitment indicates that the first distributed resource device  
30 modified how much of the resource was consumed at the first location during the first time interval.

**[0089]** Any and all combinations of any of the claim elements recited in any of the claims and/or any elements described in this application, in any fashion, fall within the contemplated scope of the present invention and protection.

**[0090]** The descriptions of the various embodiments have been presented for purposes of illustration, but are not intended to be exhaustive or limited to the 5 embodiments disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art without departing from the scope and spirit of the described embodiments.

**[0091]** Aspects of the present embodiments may be embodied as a system, method or computer program product. Accordingly, aspects of the present disclosure 10 may take the form of an entirely hardware embodiment, an entirely software embodiment (including firmware, resident software, micro-code, etc.) or an embodiment combining software and hardware aspects that may all generally be referred to herein as a "module" or "system." In addition, any hardware and/or 15 software technique, process, function, component, engine, module, or system described in the present disclosure may be implemented as a circuit or set of circuits. Furthermore, aspects of the present disclosure may take the form of a computer program product embodied in one or more computer readable medium(s) having computer readable program code embodied thereon.

**[0092]** Any combination of one or more computer readable medium(s) may be 20 utilized. The computer readable medium may be a computer readable signal medium or a computer readable storage medium. A computer readable storage medium may be, for example, but not limited to, an electronic, magnetic, optical, electromagnetic, infrared, or semiconductor system, apparatus, or device, or any suitable combination 25 of the foregoing. More specific examples (a non-exhaustive list) of the computer readable storage medium would include the following: an electrical connection having one or more wires, a portable computer diskette, a hard disk, a random access memory (RAM), a read-only memory (ROM), an erasable programmable read-only memory (EPROM or Flash memory), an optical fiber, a portable compact disc read-only memory (CD-ROM), an optical storage device, a magnetic storage device, or any 30 suitable combination of the foregoing. In the context of this document, a computer readable storage medium may be any tangible medium that can contain, or store a

program for use by or in connection with an instruction execution system, apparatus, or device.

**[0093]** Aspects of the present disclosure are described above with reference to flowchart illustrations and/or block diagrams of methods, apparatus (systems) and computer program products according to embodiments of the disclosure. It will be understood that each block of the flowchart illustrations and/or block diagrams, and combinations of blocks in the flowchart illustrations and/or block diagrams, can be implemented by computer program instructions. These computer program instructions may be provided to a processor of a general purpose computer, special purpose computer, or other programmable data processing apparatus to produce a machine. The instructions, when executed via the processor of the computer or other programmable data processing apparatus, enable the implementation of the functions/acts specified in the flowchart and/or block diagram block or blocks. Such processors may be, without limitation, general purpose processors, special-purpose processors, application-specific processors, or field-programmable gate arrays.

**[0094]** The flowchart and block diagrams in the figures illustrate the architecture, functionality, and operation of possible implementations of systems, methods and computer program products according to various embodiments of the present disclosure. In this regard, each block in the flowchart or block diagrams may represent a module, segment, or portion of code, which comprises one or more executable instructions for implementing the specified logical function(s). It should also be noted that, in some alternative implementations, the functions noted in the block may occur out of the order noted in the figures. For example, two blocks shown in succession may, in fact, be executed substantially concurrently, or the blocks may sometimes be executed in the reverse order, depending upon the functionality involved. It will also be noted that each block of the block diagrams and/or flowchart illustration, and combinations of blocks in the block diagrams and/or flowchart illustration, can be implemented by special purpose hardware-based systems that perform the specified functions or acts, or combinations of special purpose hardware and computer instructions.

**[0095]** While the preceding is directed to embodiments of the present disclosure, other and further embodiments of the disclosure may be devised without departing

from the basic scope thereof, and the scope thereof is determined by the claims that follow.



**WHAT IS CLAIMED IS:**

1. A computer-implemented method for validating distributed resource device commitments, the method comprising:

determining that a first commitment received from a first distributed resource  
5 device indicates that the first distributed resource device modified how  
much of a resource was consumed at a first location during a first time  
interval;

generating first metrology data that indicates how much of the resource was  
consumed at the first location during the first time interval; and

10 validating the first commitment based on the first metrology data.

2. The computer-implemented method of claim 1, wherein validating the first  
commitment comprises generating a first validated commitment confirming that the  
first commitment indicates that the first distributed resource device modified how  
15 much of the resource was consumed at the first location during the first time interval.

3. The computer-implemented method of claim 2, further comprising:  
generating a first distributed ledger transaction based on the first validated  
commitment; and

20 transmitting the first distributed ledger transaction to one or more nodes  
included in a distributed ledger network.

4. The computer-implemented method of claim 1, wherein validating the first  
commitment comprises:

25 identifying a first event that occurs at the first location based on the first  
metrology data; and

determining that the first event indicates that the first distributed resource  
device modified how much of the resource was consumed at the first  
location during the first time interval.

30 5. The computer-implemented method of claim 4, wherein determining that the  
first event indicates that the first distributed resource device modified how much of the  
resource was consumed at the first location during the first time interval comprises  
mapping the first event to a first event model included in a library of event models,

wherein the first event model indicates at least one operational attribute of the first distributed resource device.

6. The computer-implemented method of claim 5, further comprising modifying  
5 the first event model based on the first event, wherein the first event model comprises a Machine Learning model.

7. The computer-implemented method of claim 1, wherein the first distributed  
10 resource device restricts resource consumption at the first location to modify how much of the resource was consumed at the first location.

8. The computer-implemented method of claim 1, wherein the first distributed  
15 resource device offsets resource consumption at the first location via generation of additional resources to modify how much of the resource was consumed at the first location.

9. The computer-implemented method of claim 1, wherein generating the first  
20 metrology data comprises measuring, in real time, one or more electrical characteristics corresponding to an electrical load associated with the first location.

10. The computer-implemented method of claim 9, wherein identifying the first  
event comprises determining that at least one of the one or more electrical characteristics exceeds a threshold value.

25 11. A non-transitory computer-readable medium storing program instructions that, when executed by a processor, causes the processor to validate distributed energy resource (DER) device commitments by performing the steps of:

30 determining that a first commitment received from a first distributed resource device indicates that the first distributed resource device modified how much of a resource was consumed at a first location during a first time interval;

generating first metrology data that indicates how much of the resource was consumed at the first location during the first time interval; and validating the first commitment based on the first metrology data.

12. The non-transitory computer-readable medium of claim 11, wherein the step of validating the first commitment comprises generating a first validated commitment confirming that the first commitment indicates that the first distributed resource device  
5 modified how much of the resource was consumed at the first location during the first time interval.

13. The non-transitory computer-readable medium of claim 11, wherein the step of validating the first commitment comprises:  
10 identifying a first event that occurs at the first location based on the first metrology data; and  
determining that the first event indicates that the first distributed resource device modified how much of the resource was consumed at the first location during the first time interval.

15 14. The non-transitory computer-readable medium of claim 13, wherein determining that the first event indicates that the first distributed resource device modified how much of the resource was consumed at the first location during the first time interval comprises mapping the first event to a first event model included in a  
20 library of event models, wherein the first event model indicates at least one operational attribute of the first distributed resource device.

15. The computer-implemented method of claim 1, wherein the first distributed resource device restricts resource consumption at the first location or generates  
25 additional resources at the location to modify how much of the resource was consumed at the first location.

16. The computer-implemented method of claim 1, wherein the first distributed resource device comprises a smart electric device, a smart water device, or a smart  
30 gas device.

17. A system, comprising:  
a memory that stores a software application; and

a processor that, when executing the software application, is configured to perform the steps of:

determining that a first commitment received from a first distributed resource device indicates that the first distributed resource device modified how much of a resource was consumed at a first location during a first time interval, and validating the first commitment based on first metrology data that indicates how much of the resource was consumed at the first location during the first time interval.

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18. The system of claim 17, wherein the processor resides within a smart utility meter that monitors resource consumption at the first location to generate the metrology data.

15

19. The system of claim 17, wherein the processor is further configured to perform the additional step of obtaining the first metrology data from a node that is coupled to a resource distribution infrastructure and monitors resource consumption at the first location to generate the metrology data.

20

20. The system of claim 17, wherein the processor validates the first commitment by:

identifying a first event that occurs at the first location based on the first metrology data;

determining that the first event indicates that the first distributed resource device modified how much of the resource was consumed at the first location during the first time interval; and

25

generating a validated commitment confirming that the first commitment indicates that the first distributed resource device modified how much of the resource was consumed at the first location during the first time interval.

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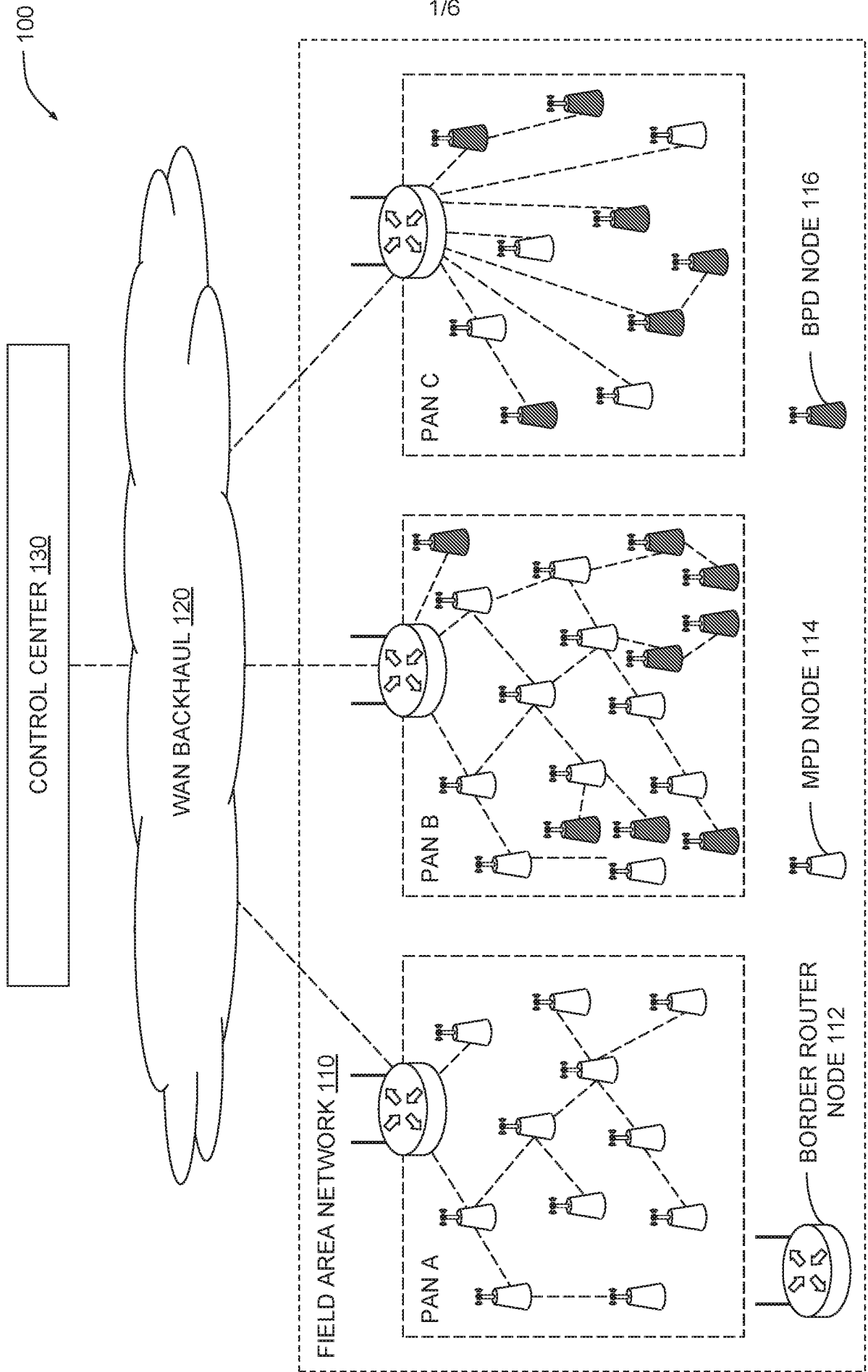


FIG. 1

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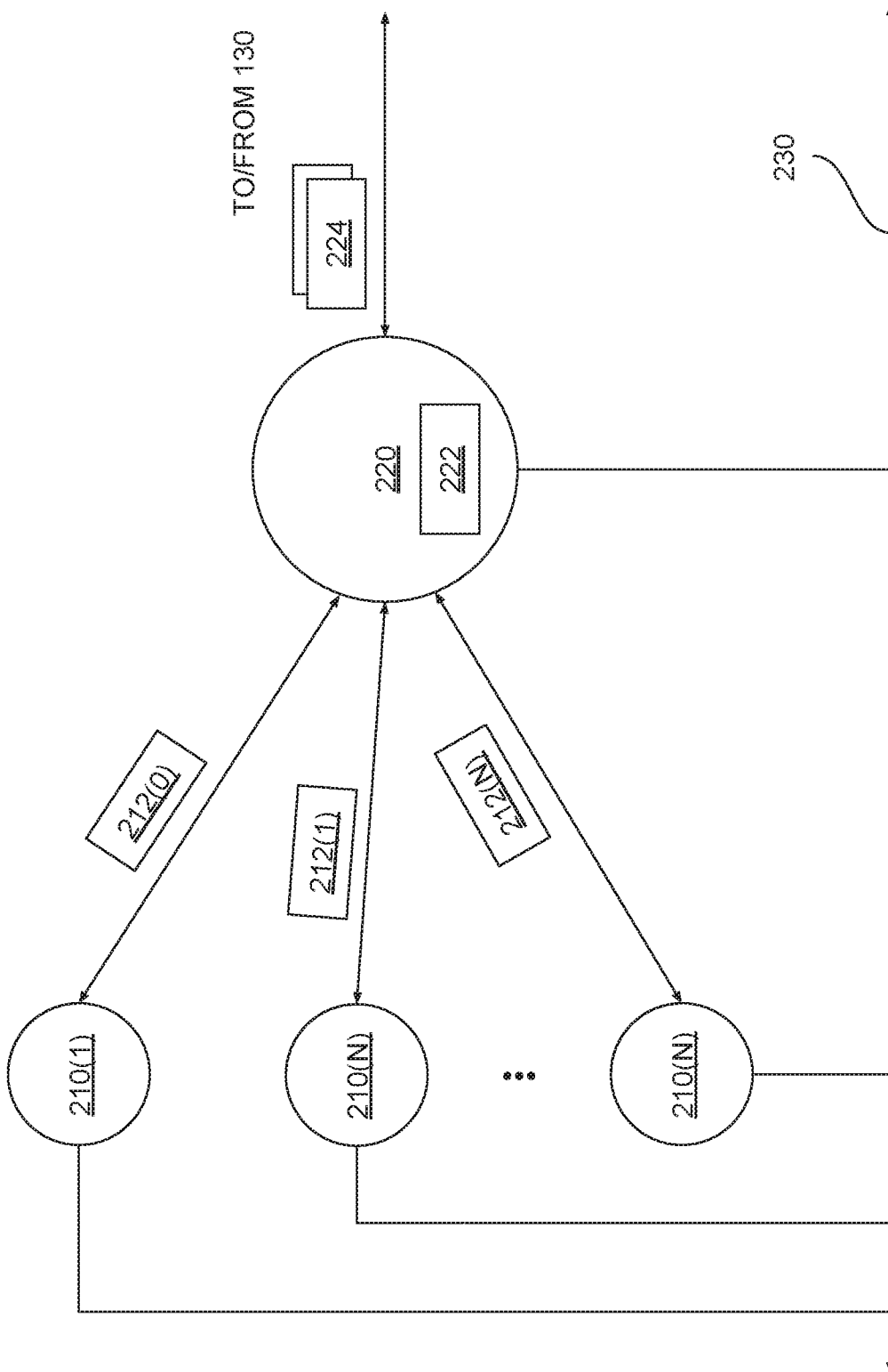


FIG. 2

220

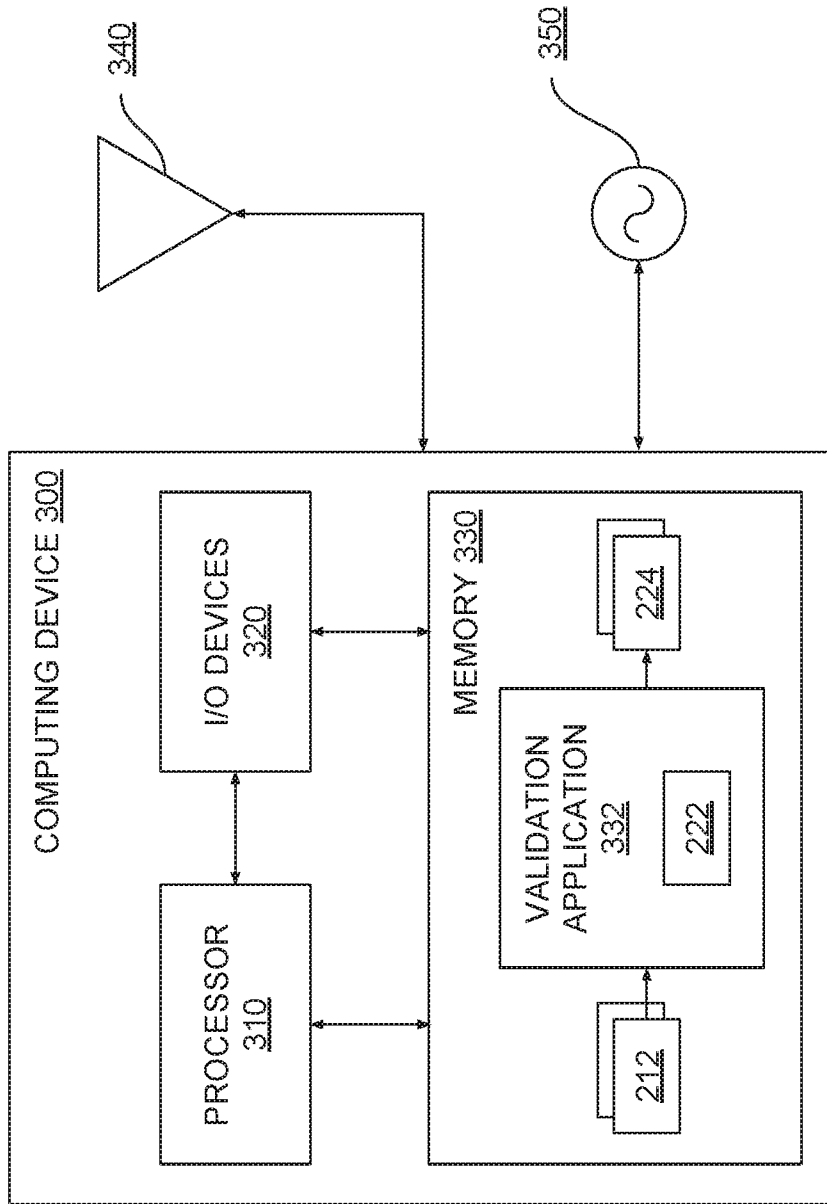


FIG. 3

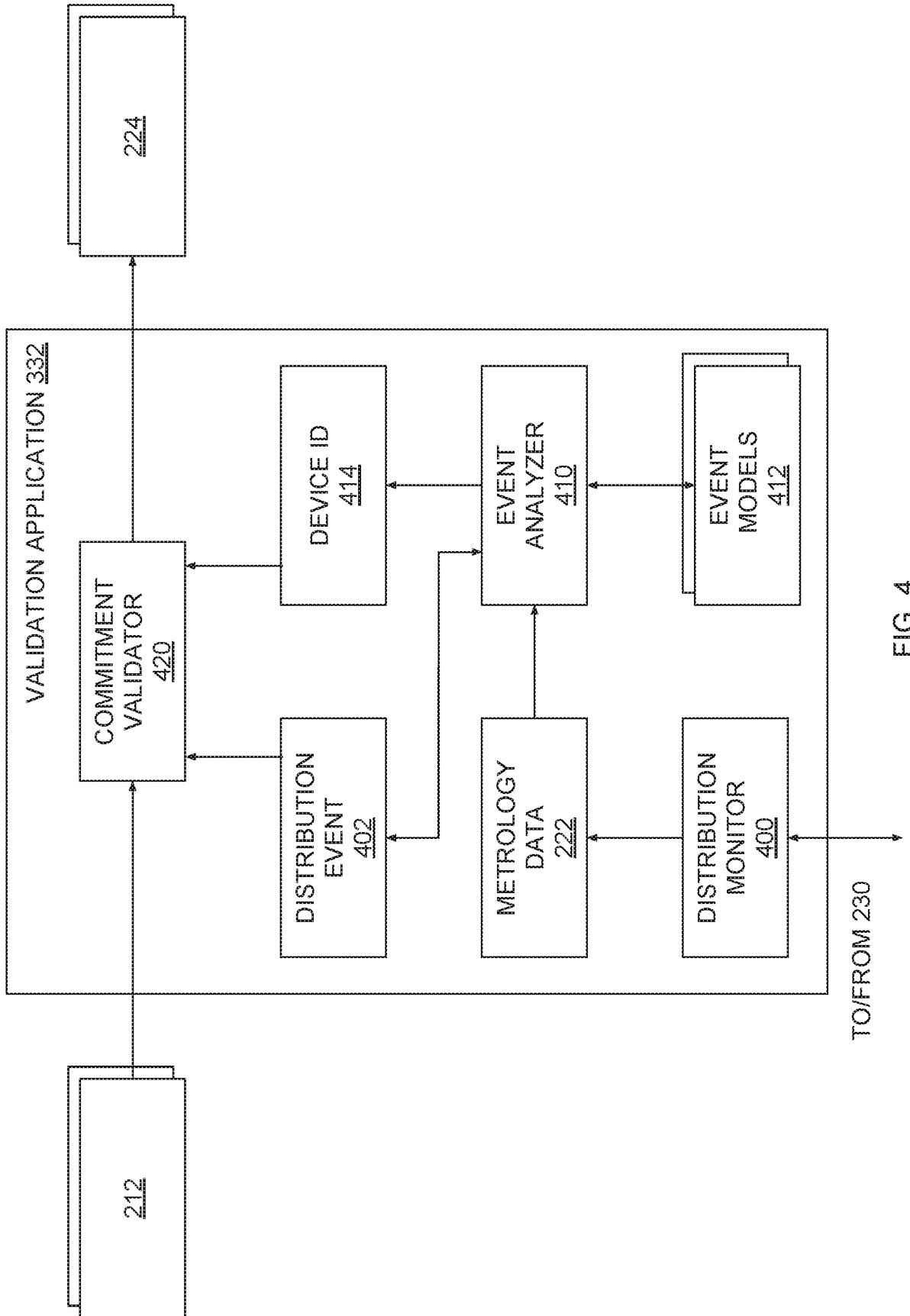


FIG. 4



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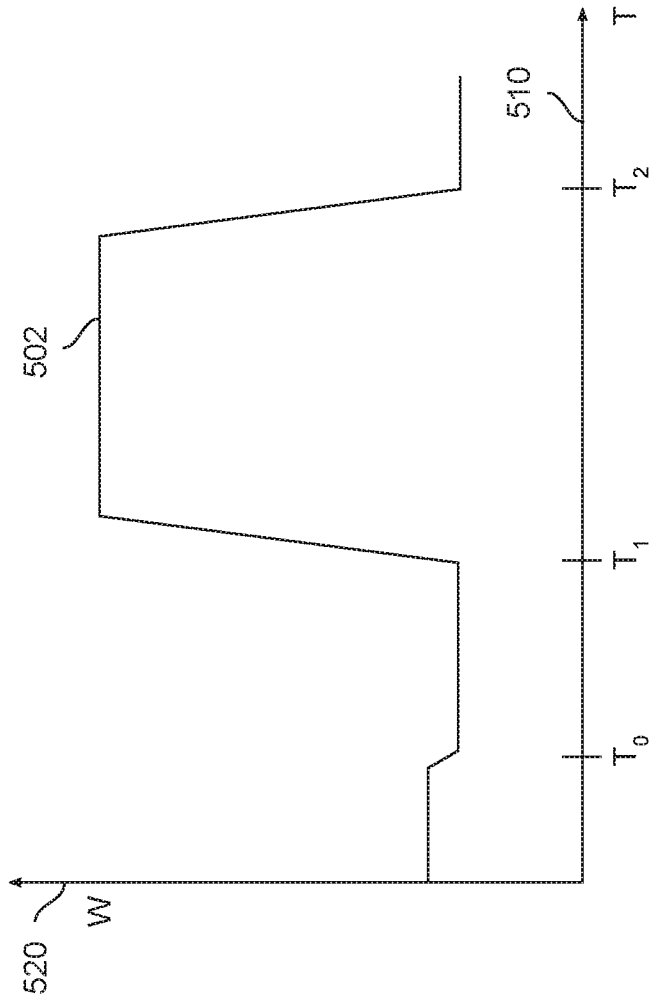


FIG. 5

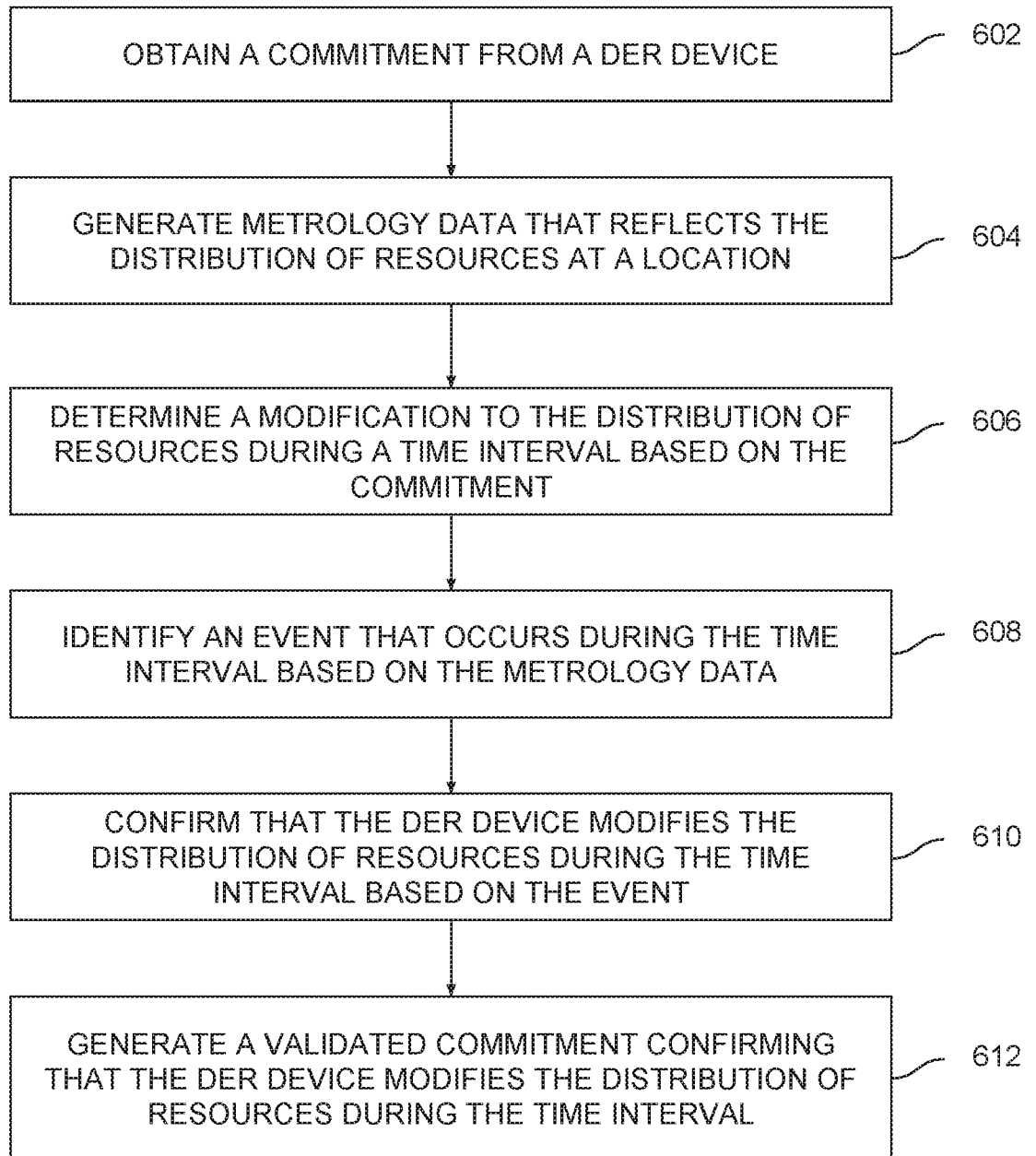


FIG. 6

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2020/016065

A. CLASSIFICATION OF SUBJECT MATTER  
 IPC(8) - G06F 5/00; G06Q 20/14; G06Q 50/06 (2020.01)  
 CPC - G06Q 20/145; G06Q 10/00; G06Q 10/06; G06Q 50/06; H02J 3/12; H02J 3/14 (2020.02)

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)

See Search History document

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

USPC - 700/22; 700/286 (keyword delimited)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

See Search History document

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US 2017/0358041 A1 (CAUSAM ENERGY, INC.) 14 December 2017 (14.12.2017) entire document	1-4, 7-13, 15-20 --- 5, 6, 14
Y	WO 2009/048963 A1 (EDSA MICRO CORPORATION) 16 April 2009 (16.04.2009) entire document	5, 6, 14
A	US 2017/0083989 A1 (CAUSAM ENERGY, INC.) 23 March 2017 (23.03.2017) entire document	1-20
A	US 2017/0206614 A1 (ELECTRONICS AND TELECOMMUNICATIONS RESEARCH INSTITUTE) 20 July 2017 (20.07.2017) entire document	1-20
A	US 2017/0160711 A1 (OPUS ONE SOLUTIONS ENERGY CORP.) 08 June 2017 (08.06.2017) entire document	1-20
A	US 2016/0198245 A1 (RHOADS et al) 07 July 2016 (07.07.2016) entire document	1-20

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

06 April 2020

Date of mailing of the international search report

**27 APR 2020**

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