US 20120133510A1

(19) United States

(12) Patent Application Publication

(10) Pub. No.: US 2012/0133510 A1

(43) Pub. Date: May 31, 2012

Pierce et al.

(54) **PHYSICAL INFRASTRUCTURE MANAGEMENT SYSTEM HAVING AN INTEGRATED CABINET**

(75) Inventors: **Alfred Pierce**, Bolingbrook, IL (US); **Brendan F. Doorhy**, Westmont, IL (US); **David C. Kilinskis**, Downers Grove, IL (US); **Donald J. Beran**, Tinley Park, IL (US); **Mark J. Donnell**, Orland Park, IL (US); **Robert Bambic**, Plainfield, IL (US); **Robert J. Pflaum**, Cedar Lake, IN (US); **Sambodhi Chatterjee**, Naperville, IL (US); **James F. Wiemeyer**, Homer Glen, IL (US)

(73) Assignee: **PANDUIT CORP.**, Tinley Park, IL (US)

(21) Appl. No.: **13/306,606**

(22) Filed: **Nov. 29, 2011**

Related U.S. Application Data

(60) Provisional application No. 61/418,189, filed on Nov. 30, 2010.

Publication Classification

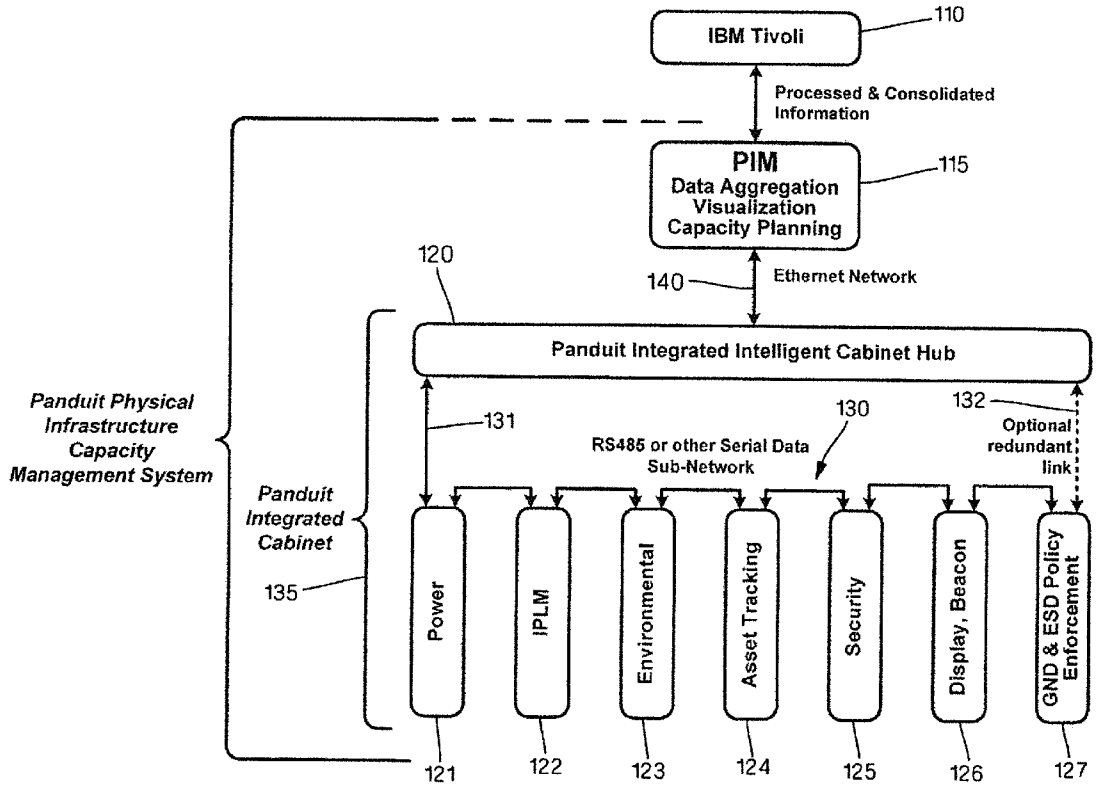
(51) **Int. Cl.**

H04Q 5/22	(2006.01)
H01R 13/44	(2006.01)
G08B 21/00	(2006.01)

(52) **U.S. Cl.** **340/540**; 340/10.1; 439/131

(57) **ABSTRACT**

A data center physical infrastructure management system has a cabinet having rack spaces and a sensor. A data communication system transmits signals to a management database. Personal or automated intervention is determined algorithmically by a data processor. A human interface for the data center management system is provided. Removable electronic assets contained in the rack spaces each have an identifier tag. An identifier tag reader is installed on the cabinet body. A door sensor provides a signal responsive to whether a cabinet door is closed, open, locked, or unlocked. Also, a secure contact arrangement has a base terminal formed of electrically conductive material, and first and second electrically conductive elements. A resilient non-conductive element is interposed between the first and second electrically conductive elements, and a compression element compresses the resilient non-conductive element to cause the first and second electrically conductive elements to communicate with one another.



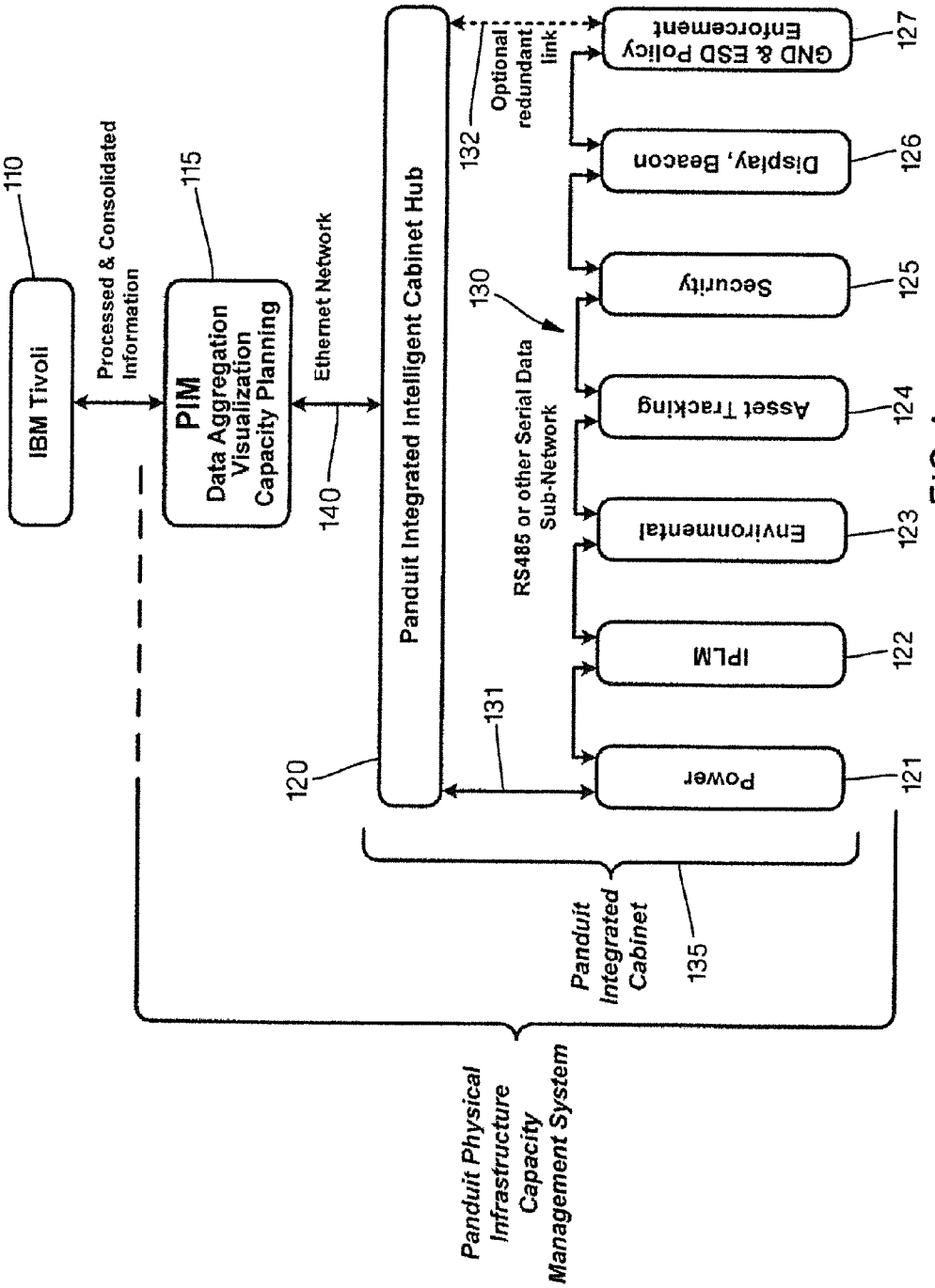

110
IBM Tivoli
Processed & Consolidated Information
115
PIM
Data Aggregation
Visualization
Capacity Planning
Ethernet Network
140
120
Panduit Integrated Intelligent Cabinet Hub
132
Optional redundant link
130
RS485 or other Serial Data Sub-Network
131
GND & ESD Policy Enforcement
127
Display, Beacon
126
Security
125
Asset Tracking
124
Environmental
123
IPLM
122
Power
121
Panduit Integrated Cabinet
135
Panduit Physical Infrastructure Capacity Management System

FIG. 1a

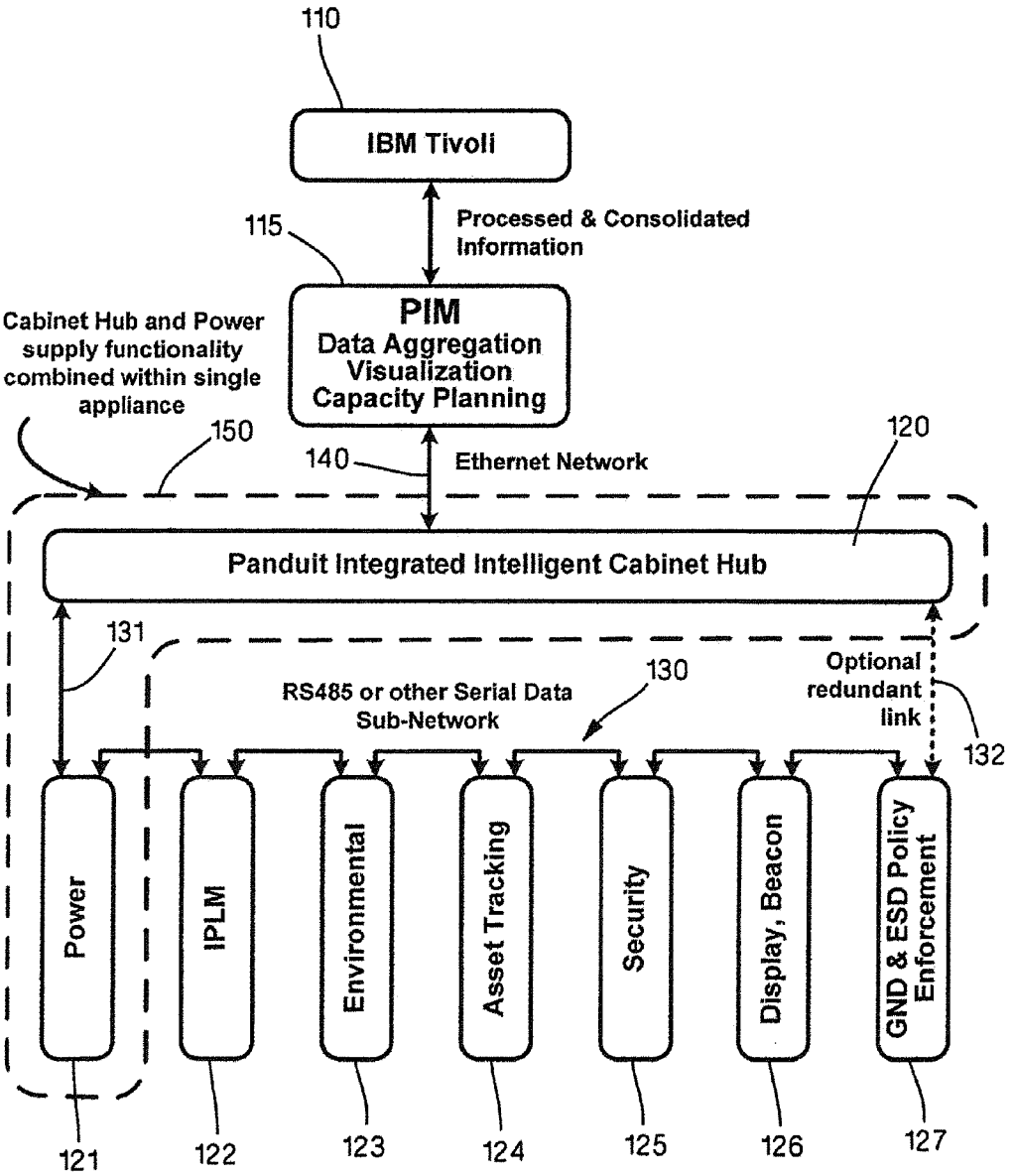

110
IBM Tivoli
115
Processed & Consolidated Information
PIM
Data Aggregation
Visualization
Capacity Planning
Cabinet Hub and Power supply functionality combined within single appliance
150
120
140
Ethernet Network
Panduit Integrated Intelligent Cabinet Hub
131
130
RS485 or other Serial Data Sub-Network
Optional redundant link
132
Power
IPLM
Environmental
Asset Tracking
Security
Display, Beacon
GND & ESD Policy Enforcement
121
122
123
124
125
126
127

FIG. 1b

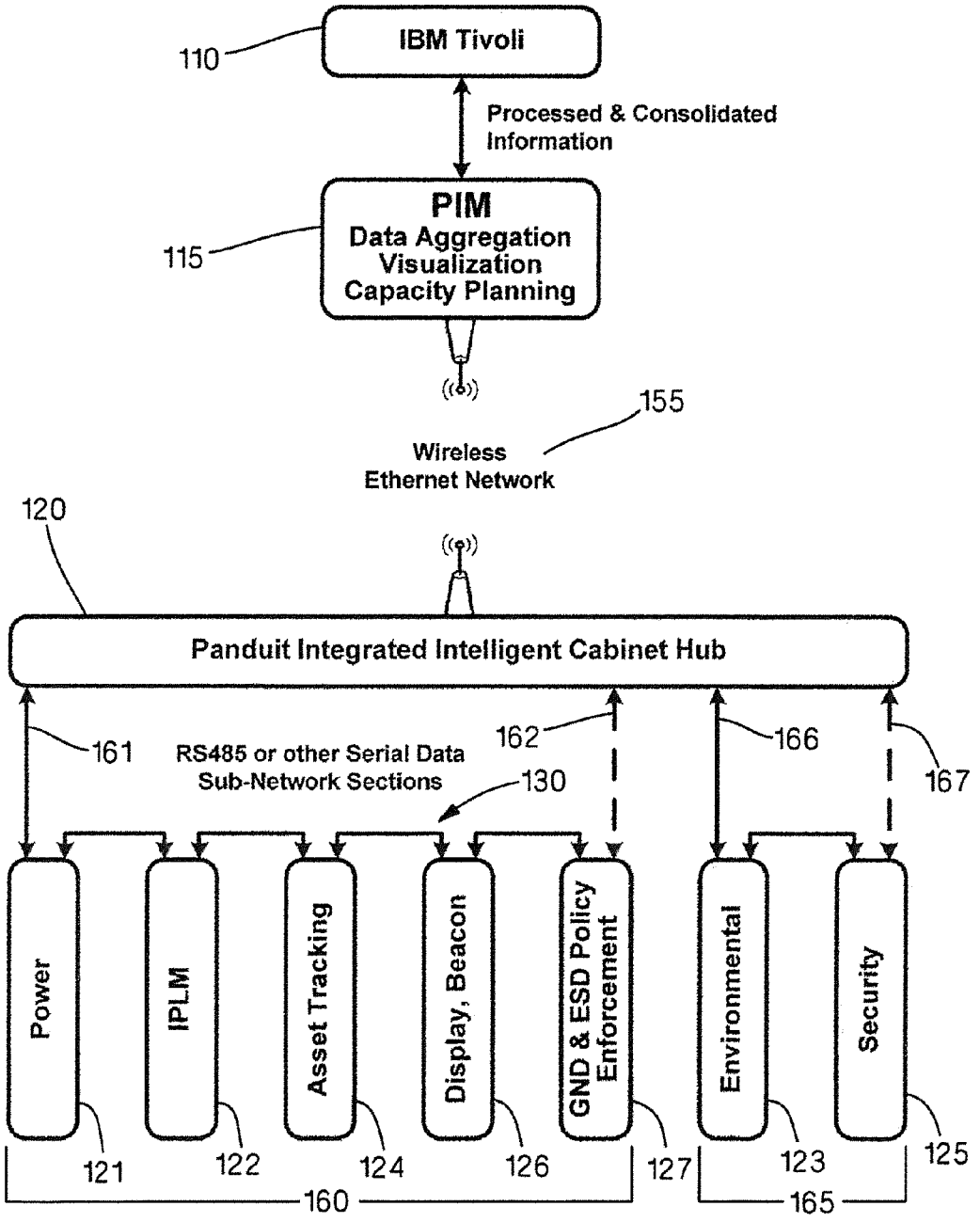

110
IBM Tivoli
Processed & Consolidated Information
115
PIM
Data Aggregation
Visualization
Capacity Planning
155
Wireless
Ethernet Network
120
Panduit Integrated Intelligent Cabinet Hub
161
RS485 or other Serial Data
Sub-Network Sections
130
162
166
167
Power
IPLM
Asset Tracking
Display, Beacon
GND & ESD Policy Enforcement
Environmental
Security
121
122
124
126
127
123
125
160
165

FIG. 1c

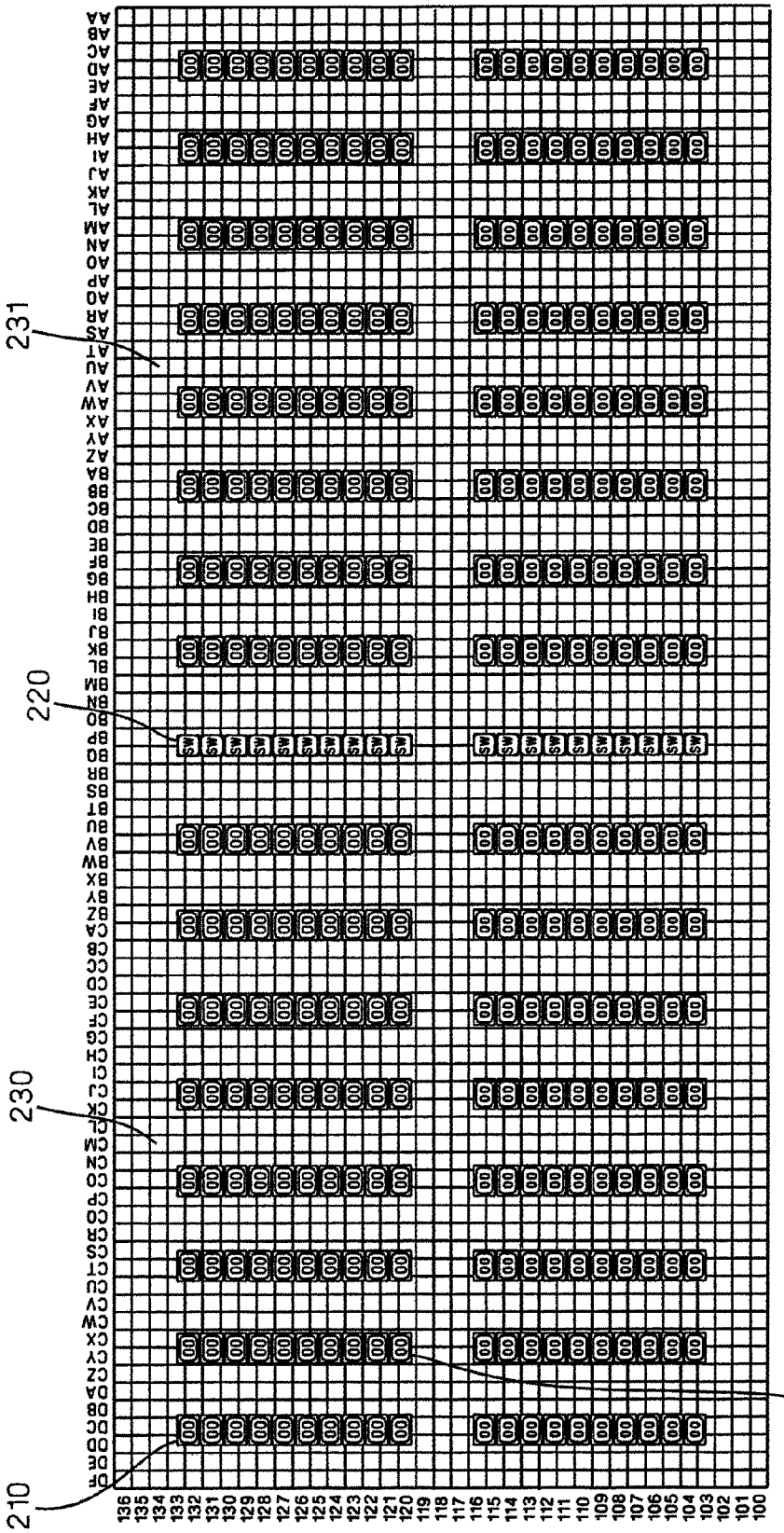


FIG.2a

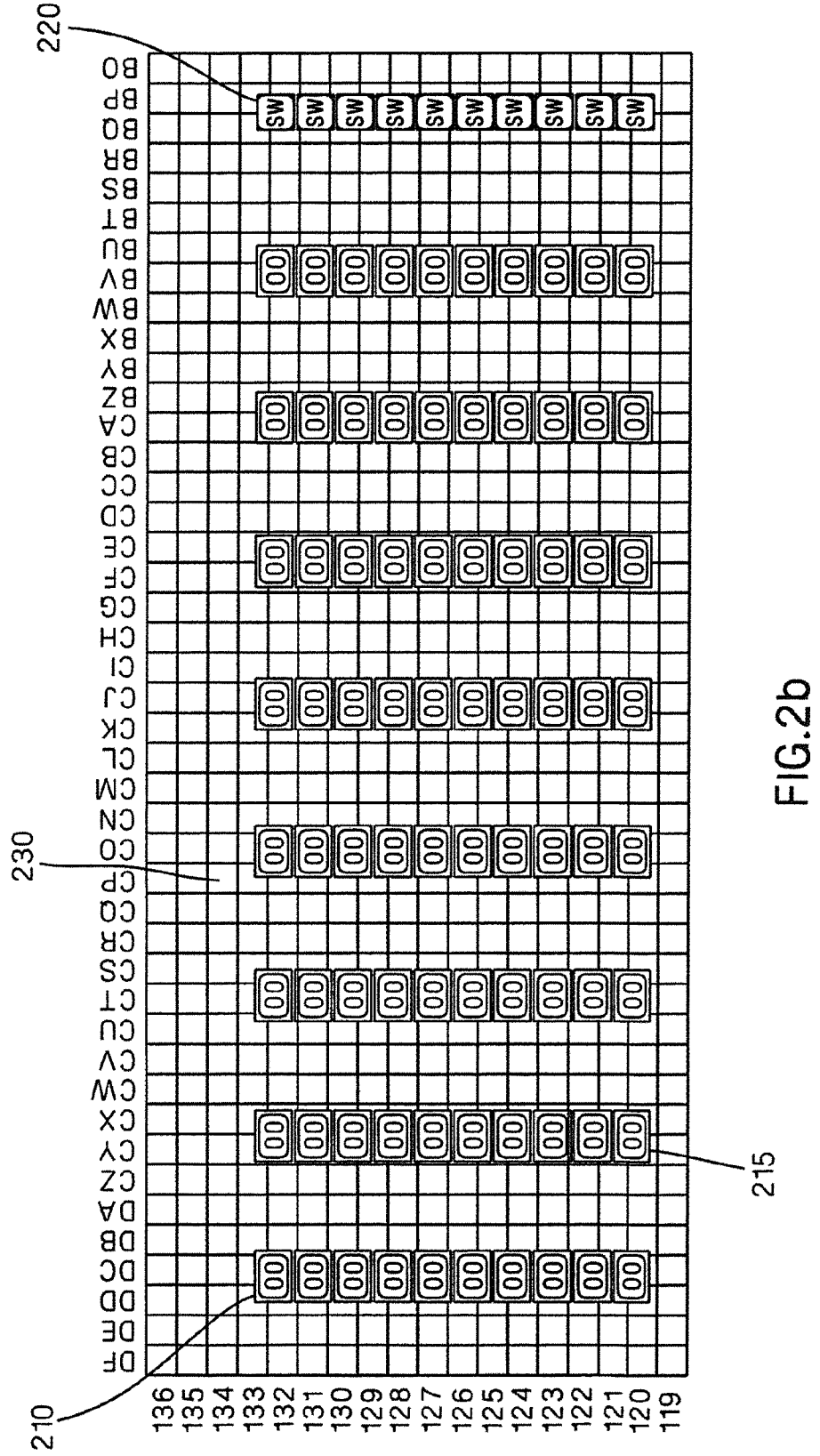

220
230
210
215
SW
00
BO
BP
BQ
BR
BS
BT
BU
BV
BW
BX
BY
BZ
CA
CB
CC
CD
CE
CF
CG
CH
CI
CJ
CK
CL
CM
CN
CO
CP
CQ
CR
CS
CT
CU
CV
CW
CX
CY
CZ
DA
DB
DC
DD
DE
DF
136
135
134
133
132
131
130
129
128
127
126
125
124
123
122
121
120
119

FIG.2b

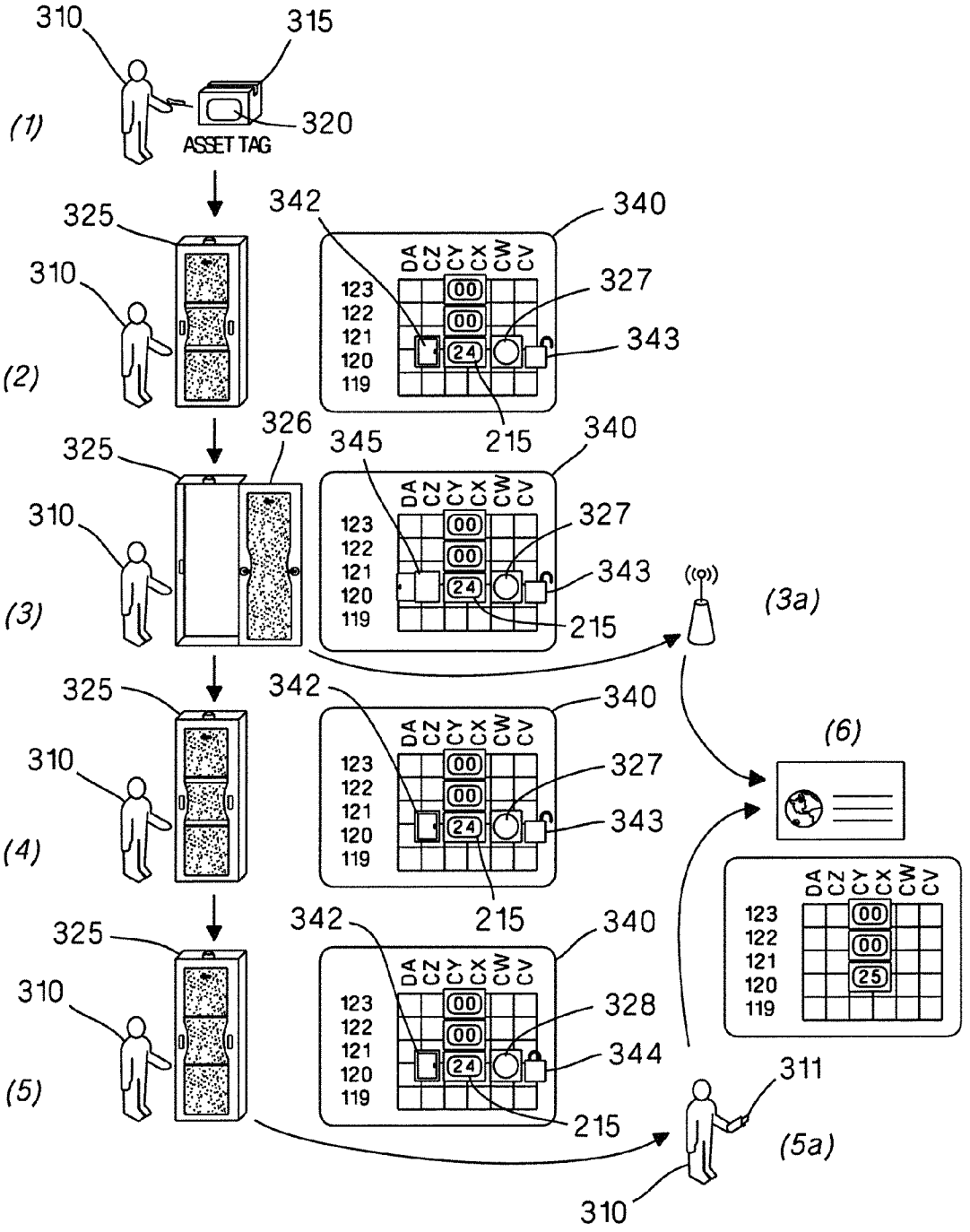

310
315
320
(1)
ASSET TAG
325
342
340
310
327
343
(2)
DA CZ CY CX CW CV
123 122 121 120 119
00 00 24
326
345
215
325
310
(3)
(3a)
325
342
340
310
(6)
327
343
(4)
215
325
342
340
310
328
344
(5)
215
311
(5a)
310
00 00 25

FIG.3a

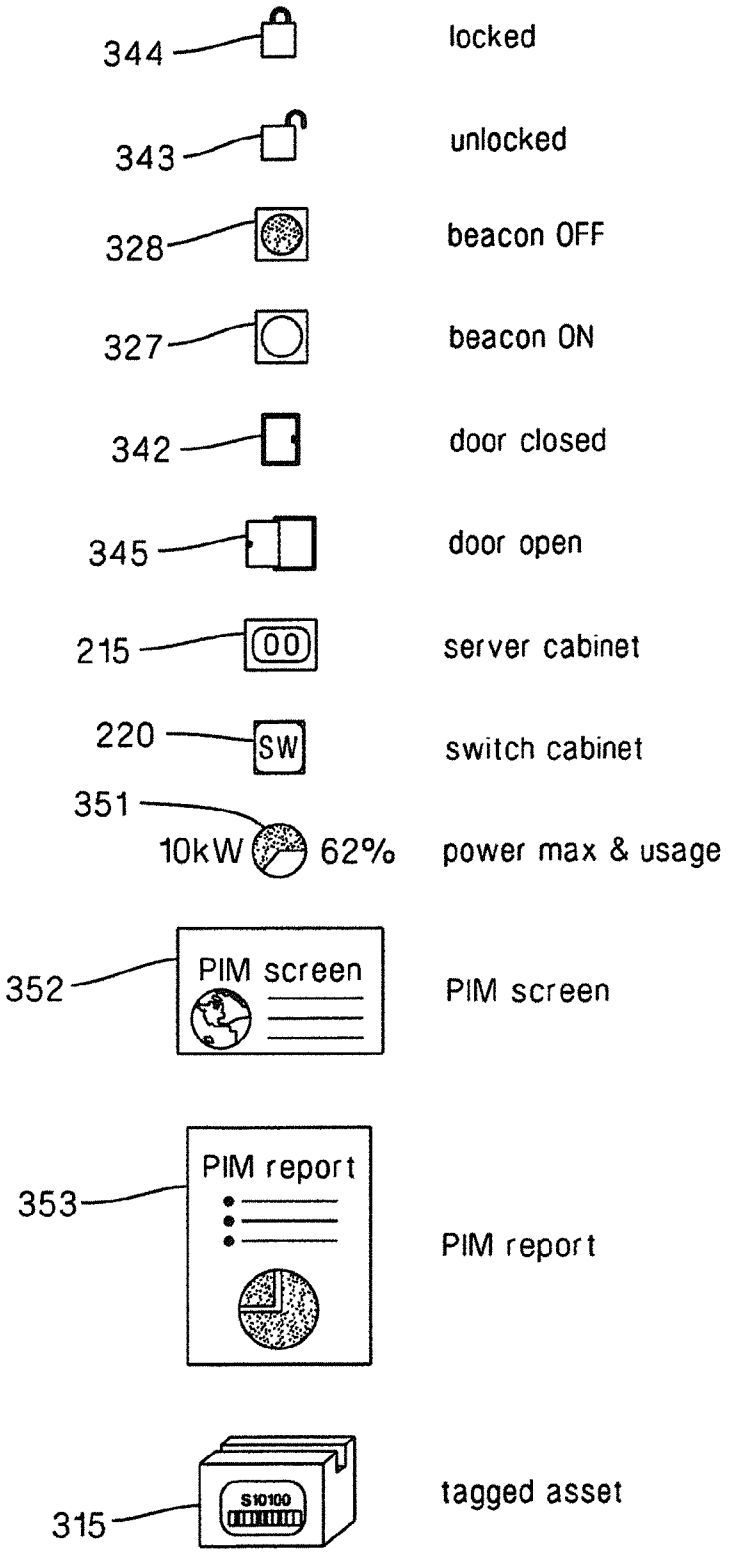

344
locked
343
unlocked
328
beacon OFF
327
beacon ON
342
door closed
345
door open
215
00
server cabinet
220
SW
switch cabinet
351
10kW
62%
power max & usage
352
PIM screen
PIM screen
353
PIM report
PIM report
315
S10100
tagged asset

FIG.3b

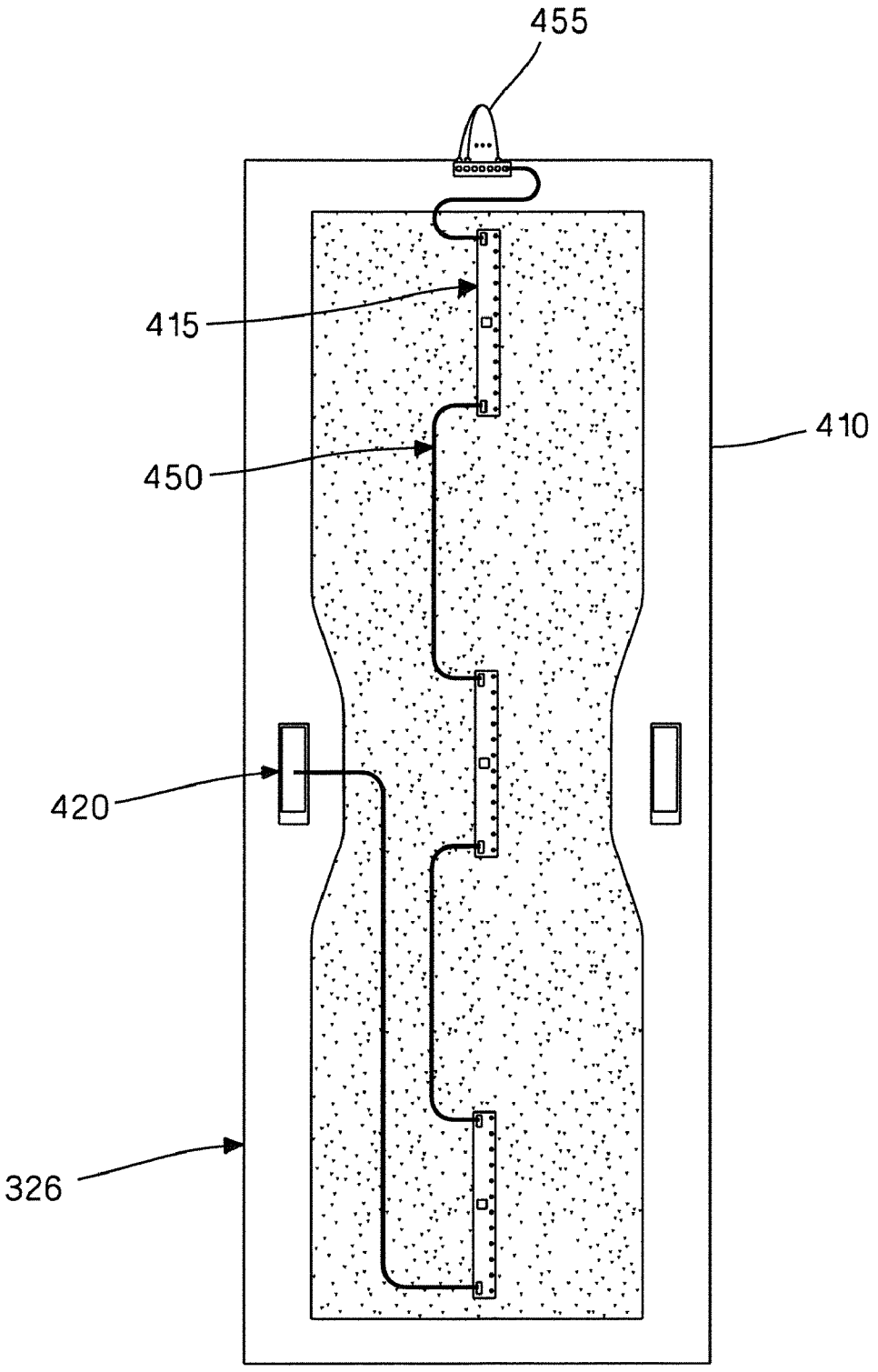


FIG.4a

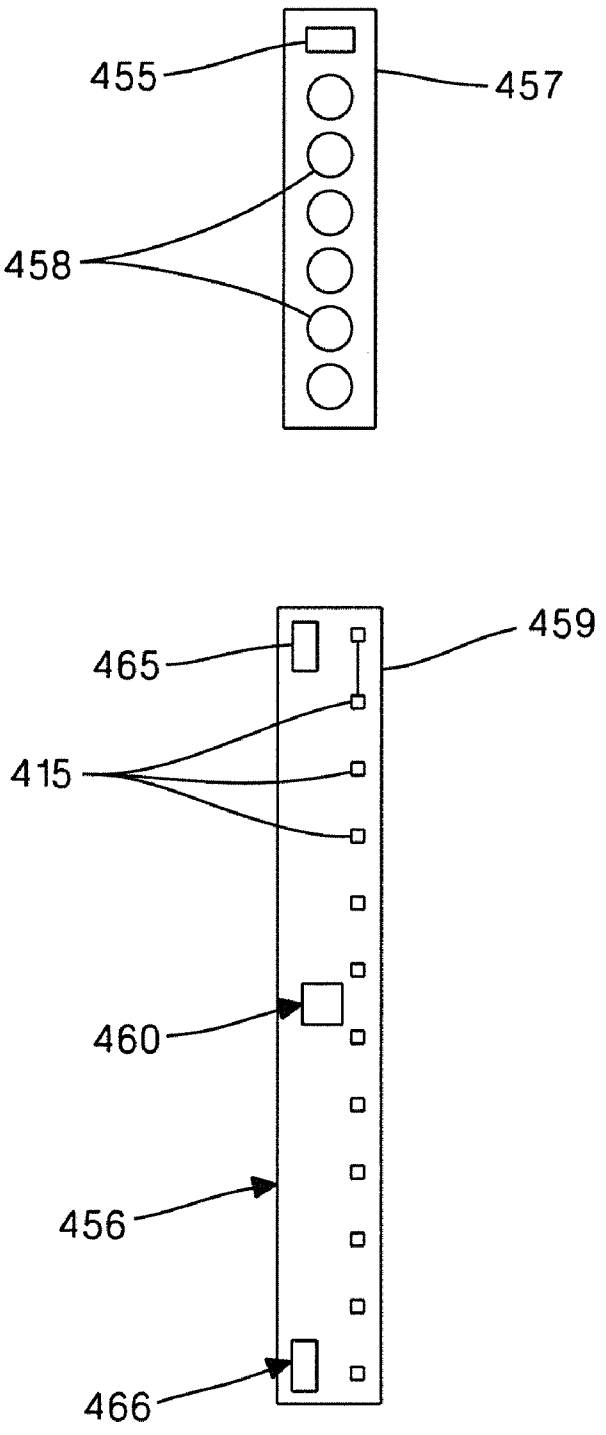


FIG.4b

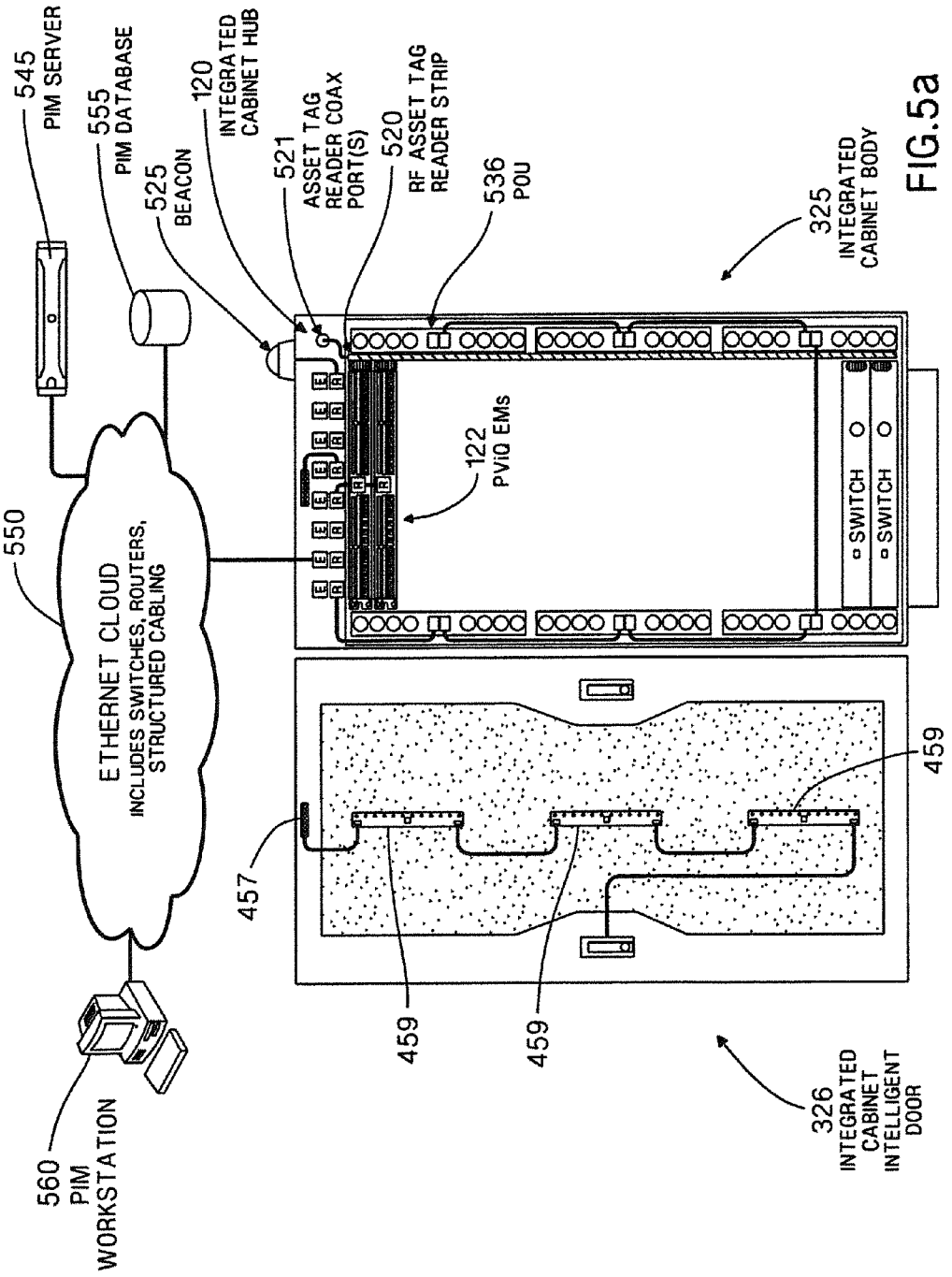

545
PIM SERVER
555
PIM DATABASE
525
BEACON
120
INTEGRATED CABINET HUB
521
ASSET TAG READER COAX PORT(S)
520
RF ASSET TAG READER STRIP
536
POU
325
INTEGRATED CABINET BODY
122
PViQ EMs
SWITCH
SWITCH
550
ETHERNET CLOUD
INCLUDES SWITCHES, ROUTERS, STRUCTURED CABLING
457
459
459
459
560
PIM WORKSTATION
326
INTEGRATED CABINET INTELLIGENT DOOR

FIG.5a

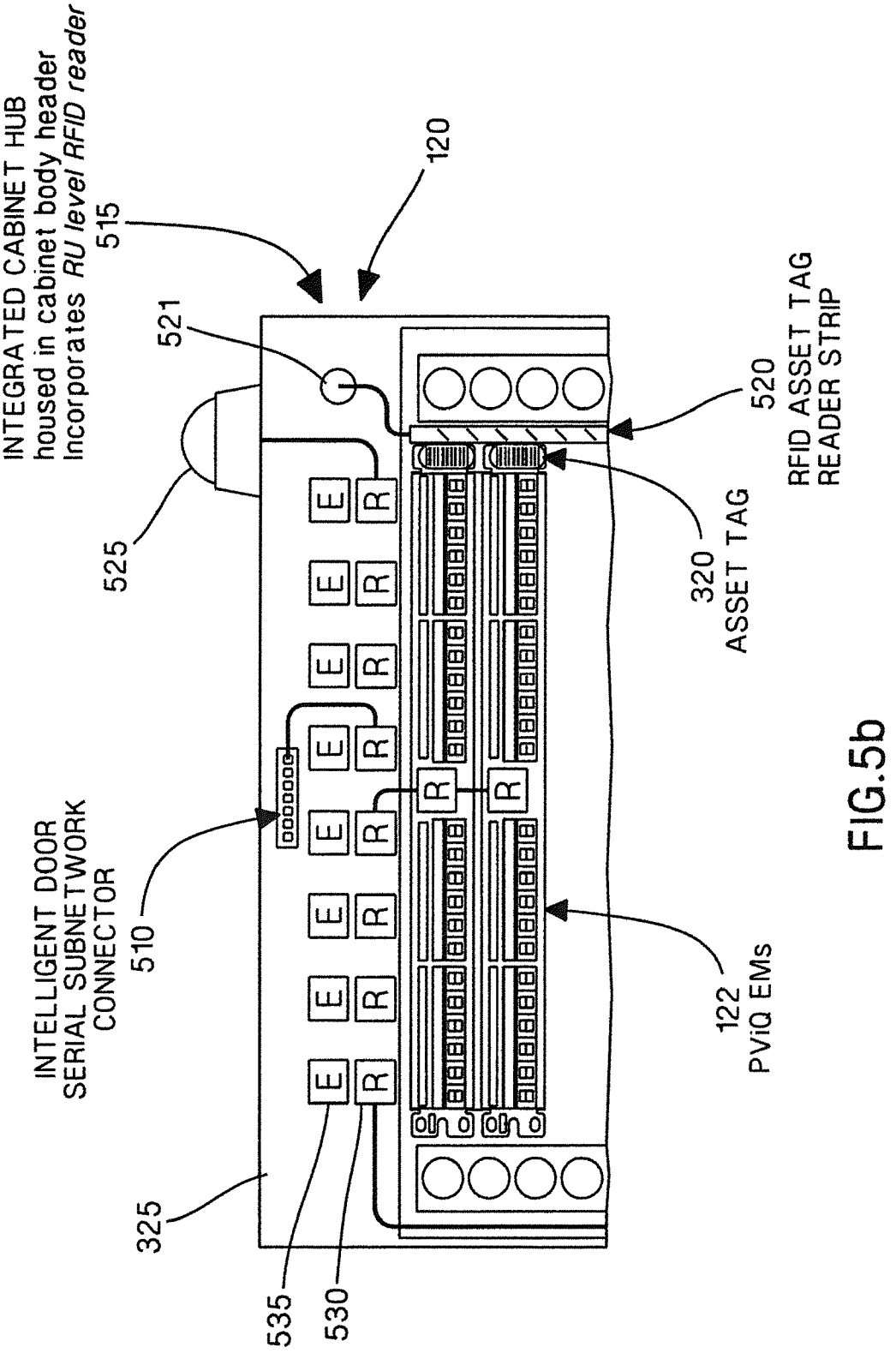

INTEGRATED CABINET HUB
housed in cabinet body header
Incorporates RU level RFID reader
515
120
521
525
520
RFID ASSET TAG
READER STRIP
320
ASSET TAG
INTELLIGENT DOOR
SERIAL SUBNETWORK
CONNECTOR
510
122
PViQ EMs
325
535
530
E
R

FIG.5b

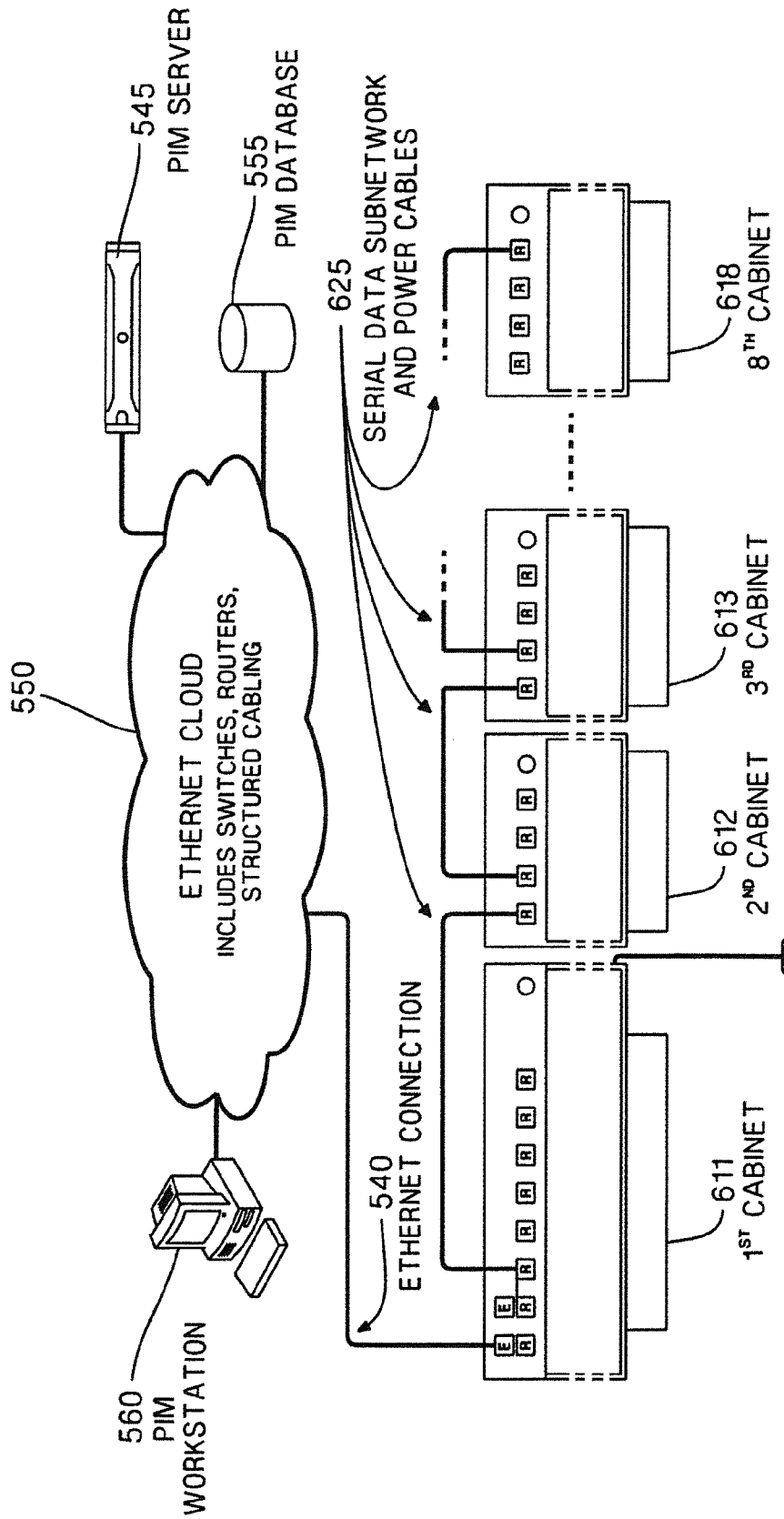

545
PIM SERVER
555
PIM DATABASE
625
SERIAL DATA SUBNETWORK
AND POWER CABLES
618
8TH CABINET
613
3RD CABINET
612
2ND CABINET
611
1ST CABINET
630
FUNCTIONAL MODULES
POWER SUPPLY CONNECTION
550
ETHERNET CLOUD
INCLUDES SWITCHES, ROUTERS,
STRUCTURED CABLING
540
ETHERNET CONNECTION
560
PIM
WORKSTATION

FIG.6

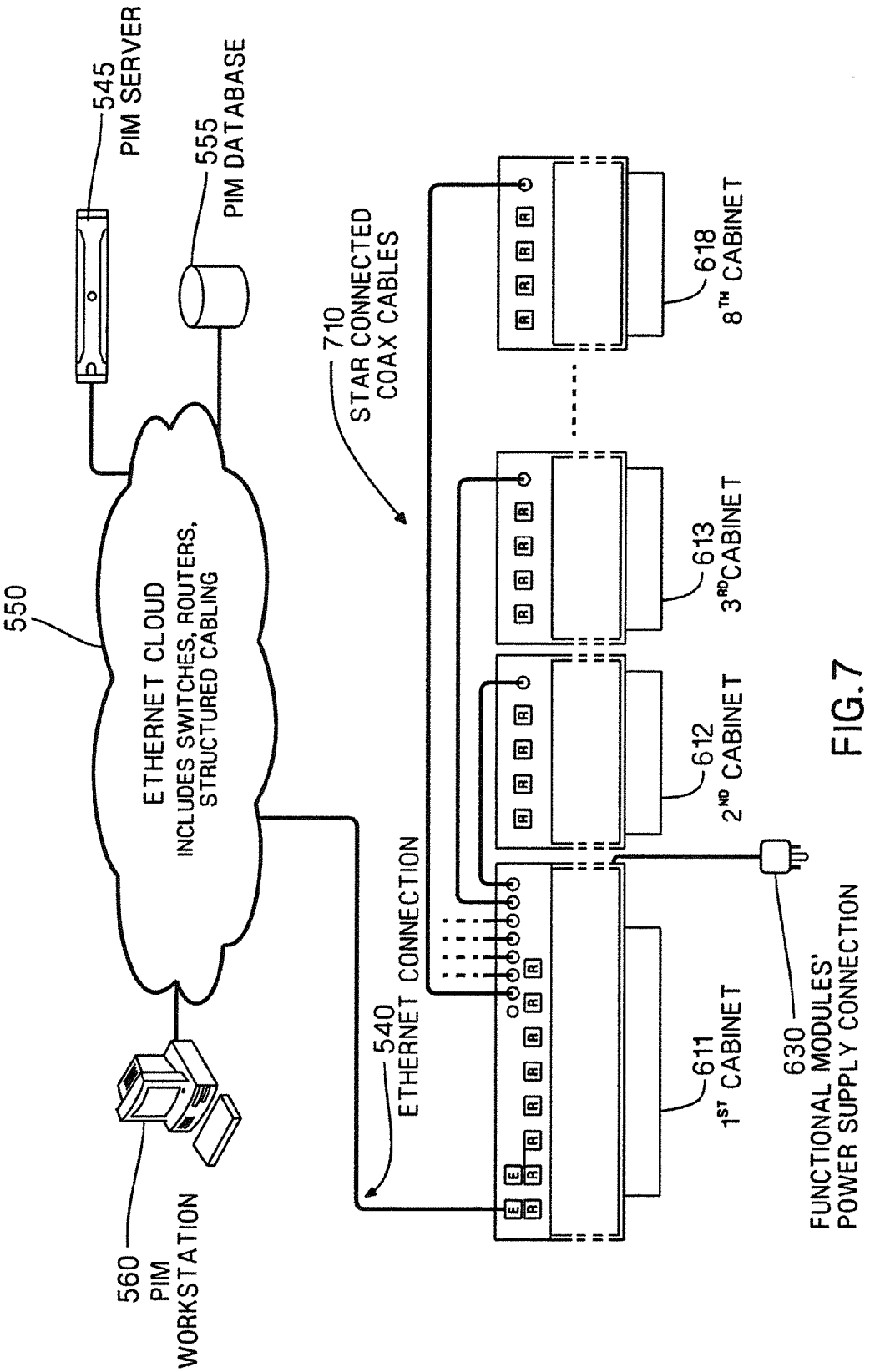

545
PIM SERVER
555
PIM DATABASE
710
STAR CONNECTED
COAX CABLES
618
8TH CABINET
613
3RD CABINET
612
2ND CABINET
611
1ST CABINET
630
FUNCTIONAL MODULES'
POWER SUPPLY CONNECTION
550
ETHERNET CLOUD
INCLUDES SWITCHES, ROUTERS,
STRUCTURED CABLING
540
ETHERNET CONNECTION
560
PIM
WORKSTATION

FIG. 7

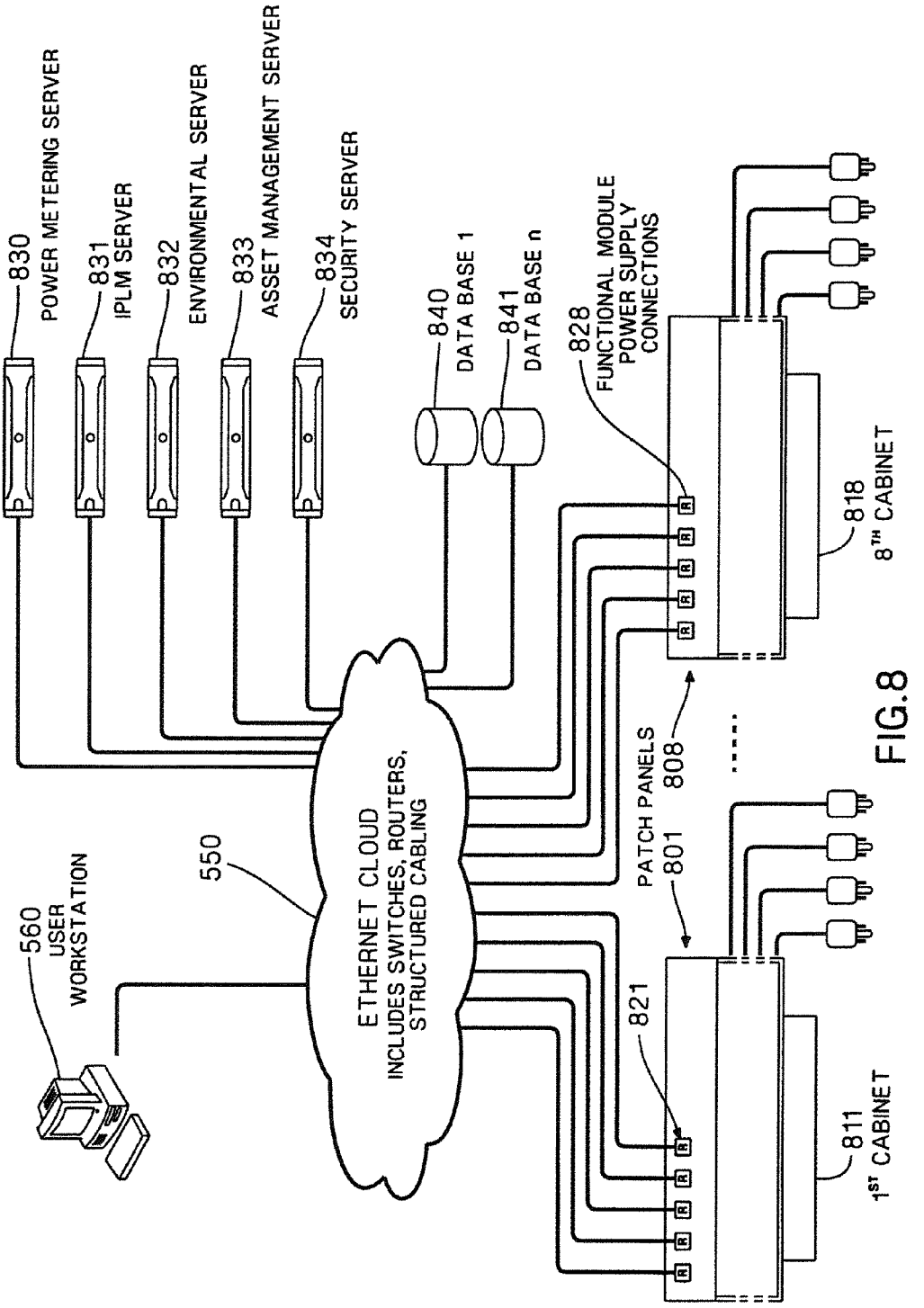

830
POWER METERING SERVER
831
IPLM SERVER
832
ENVIRONMENTAL SERVER
833
ASSET MANAGEMENT SERVER
834
SECURITY SERVER
840
DATA BASE 1
841
DATA BASE n
828
FUNCTIONAL MODULE POWER SUPPLY CONNECTIONS
818
8TH CABINET
808
PATCH PANELS
801
821
811
1ST CABINET
550
ETHERNET CLOUD
INCLUDES SWITCHES, ROUTERS, STRUCTURED CABLING
560
USER WORKSTATION

FIG.8

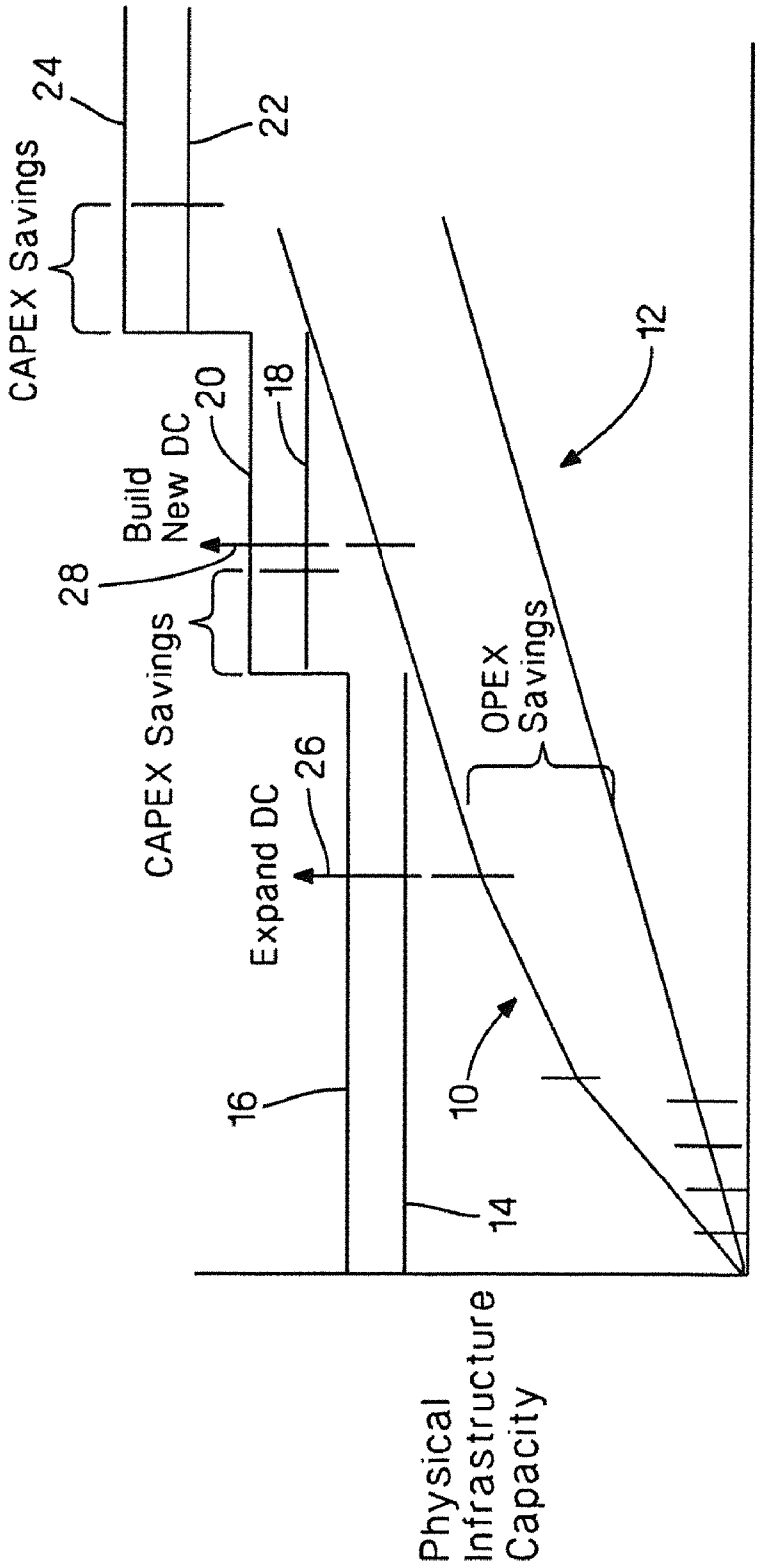

Physical Infrastructure Capacity
Time
10
12
14
16
18
20
22
24
26
28
CAPEX Savings
Build New DC
CAPEX Savings
Expand DC
OPEX Savings

FIG.9

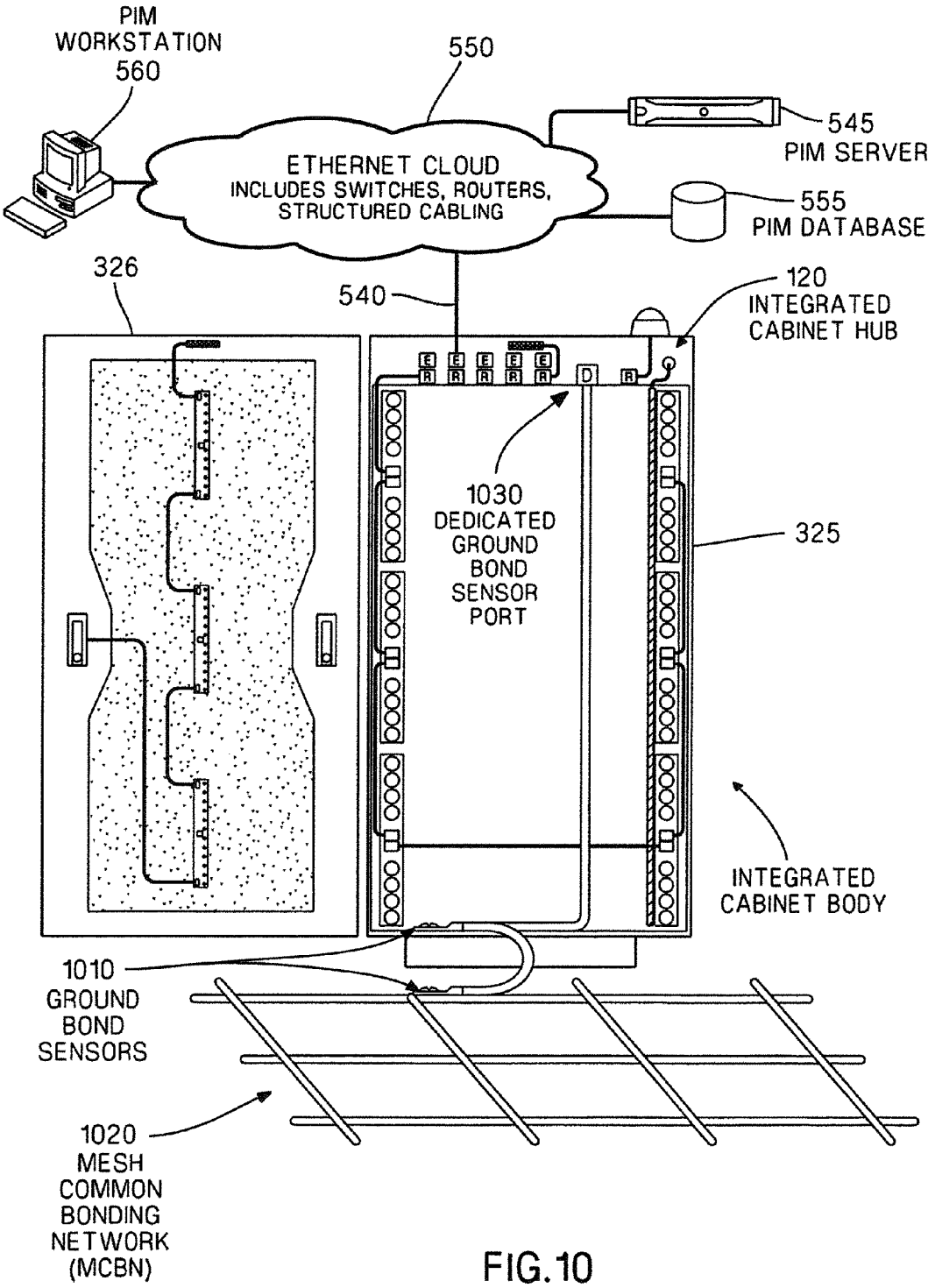

PIM
WORKSTATION
560
550
545
PIM SERVER
ETHERNET CLOUD
INCLUDES SWITCHES, ROUTERS,
STRUCTURED CABLING
555
PIM DATABASE
326
540
120
INTEGRATED
CABINET HUB
1030
DEDICATED
GROUND
BOND
SENSOR
PORT
325
INTEGRATED
CABINET BODY
1010
GROUND
BOND
SENSORS
1020
MESH
COMMON
BONDING
NETWORK
(MCBN)

FIG.10

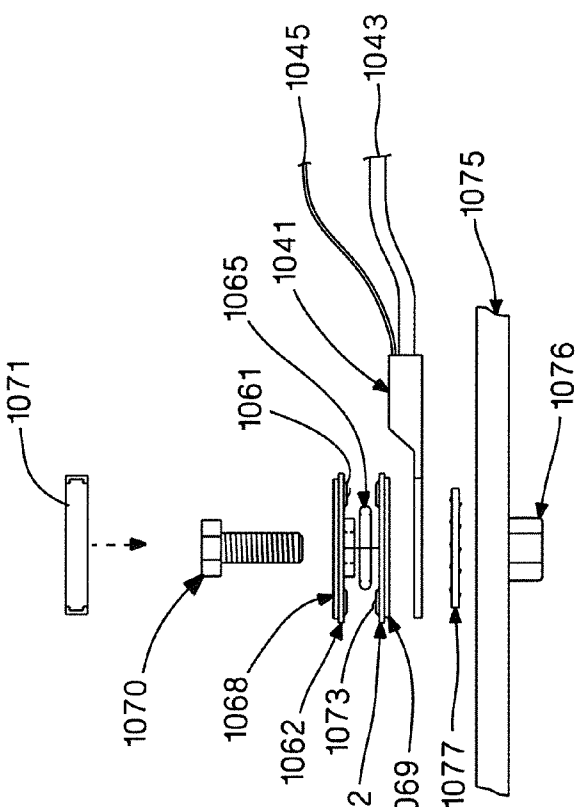


FIG.11a

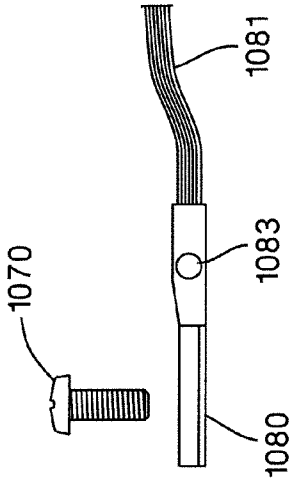


FIG.11c

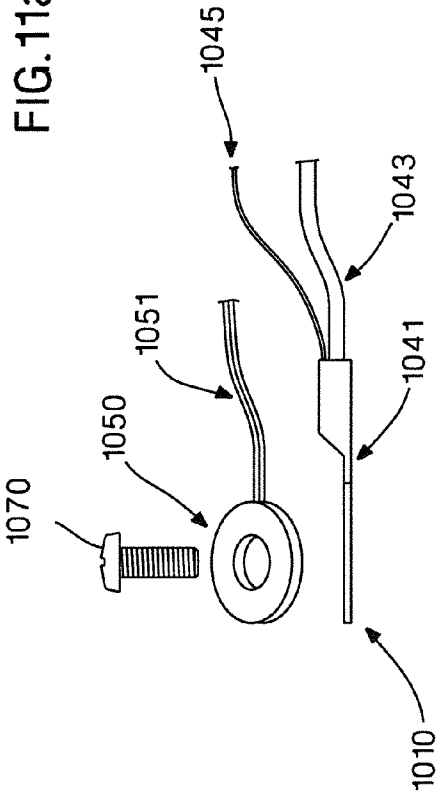


FIG.11b

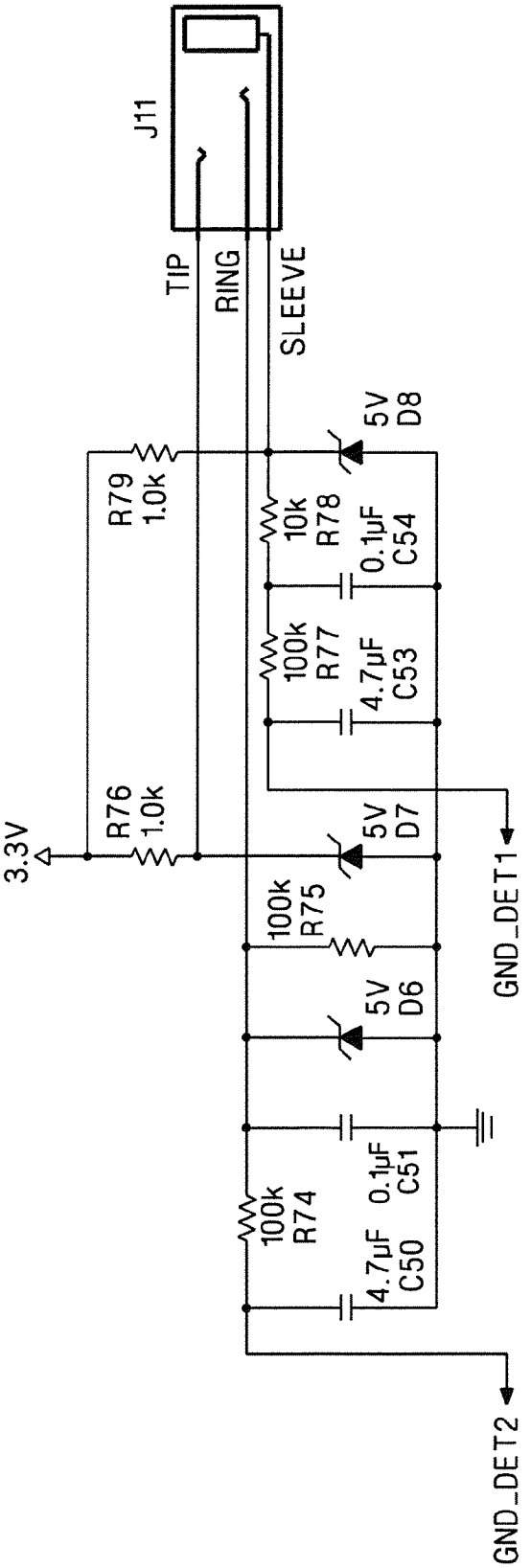

J11
TIP
RING
SLEEVE
3.3V
R79
1.0k
R76
1.0k
10k
R78
100k
R77
100k
R75
100k
R74
0.1µF
C54
4.7µF
C53
0.1µF
C51
4.7µF
C50
5V
D8
5V
D7
5V
D6
GND_DET1
GND_DET2

FIG. 12

PHYSICAL INFRASTRUCTURE MANAGEMENT SYSTEM HAVING AN INTEGRATED CABINET

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Provisional Application No. 61/418,189, filed Nov. 30, 2010 and entitled "Physical Infrastructure Management System Having An Integrated Cabinet", the subject matter of which is incorporated by reference in its entirety

[0002] This application incorporates by reference in its entirety U.S. patent application Ser. No. 12/332,900 filed Dec. 11, 2008 and entitled "Physical Infrastructure Management System."

BACKGROUND

[0003] Servers within data centers often process high value information, and many organizations' revenues depend upon continuous, uninterrupted processing of that data. Power metering, IPLM (Intelligent Physical Layer Management), environmental control, asset tracking, and security measures reduce unnecessary operational risk, along with its associated potential negative impacts to the organization and its customers.

[0004] Information technology staff must also determine existing, new and planned equipment venues quickly and accurately. Such timely determinations save operational expense, facilitate uninterrupted continuity of business operations, and increase the return on the ongoing investment in data centers.

SUMMARY

[0005] In accordance with the invention, there is provided a data center physical infrastructure capacity management system that is managed by IT personnel. The system includes a server cabinet having rack spaces and a sensor. A data communication arrangement propagates communications signals from the sensor to a management database that receives information from the communications signals, the received information being stored. A data processor determines algorithmically the need for intervention to the data center physical infrastructure, which may take the form of changes to the physical infrastructure, and issuance of alerts to IT personnel. A human interface enables human interaction with the data center management system.

[0006] In one embodiment, the received information corresponds to environmental data.

[0007] In a further embodiment, the intervention that may be required by the data processor is determined to be a selectable one of human and automated intervention.

[0008] The intervention determined by said data processor may take the additional form of changes to the representative underlying data center system management database. The human interface, in one embodiment, employs a graphical user interface that displays icons representative of predetermined condition states of the data center.

[0009] The data processor in an advantageous embodiment of the invention includes a computer, and the algorithmic determination of the need for intervention is responsive to any combination of temperature data; humidity data; a sensor address; a device serial number; the adequacy of a system ground connection; and the number of occupied rack spaces.

[0010] In accordance with a further apparatus aspect of the invention, there is provided a cabinet for holding removable electronic assets. In accordance with this aspect of the embodiment, there is provided a cabinet body having a plurality of rack spaces, each rack space accommodating one of the removable electronic assets. A plurality of identifier tags are attached to respectively associated ones of the removable electronic assets, and an identifier tag reader that is installed on the cabinet body communicates with at least one of the identifier tags, providing a tag reader electrical signal responsive to the communication with the at least one of said plurality of identifier tags. A cabinet door is attached to the cabinet body, and a door sensor provides an electrical signal responsive to closed, open, locked, and unlocked states of the cabinet door.

[0011] In one embodiment of this further aspect of the invention, there is further provided a data output for providing data responsive to the tag reader electrical signal. A database stores asset information responsive to the presence of the removable electronic assets in respective ones of the rack spaces. The asset information is obtained from the tag reader electrical signal, which is itself derived from the identifier tag reader.

[0012] In a further embodiment, the identifier tag reader is an elongated antenna element that is affixed to the cabinet body and extends proximal to a plurality of the rack spaces.

[0013] In a further embodiment of the invention, the database is maintained in a remote server that can be accessed wirelessly or over the interne.

[0014] The cabinet of an embodiment of the invention additionally has an integrated cabinet hub disposed in the server cabinet for coordinating respective data signals from any combination of: a power monitoring arrangement; a physical layer management system; an environmental control system; an asset tracking system; a grounding monitoring system; and a security system.

[0015] In accordance with an advantageous embodiment of the invention, there is provided a wireless communication arrangement for delivering data from the integrated cabinet hub to a physical infrastructure management system. A monitoring arrangement, has a graphical user interface that displays icons representative of predetermined condition states of the cabinet.

[0016] In an advantageous embodiment, there is provided an environmental sensor installed on the cabinet door. Also, an electrical contact arrangement having a cabinet door portion and a cabinet body portion conducts signals from the environmental sensor that contain environmental information to the cabinet body. Additionally, in some embodiments, there is further provided a credentials monitoring arrangement for controlling the state of the cabinet door.

[0017] There is additionally provided a secure contact arrangement that has a base terminal formed of electrically conductive material and first and second electrically conductive elements. A resilient non-conductive element is interposed between the first and second electrically conductive elements. A compression element applies an axial force through the first electrically conductive element, the resilient non-conductive element, the second electrically conductive element, and the base terminal. The applied axial force compresses the resilient non-conductive element to cause the first and second electrically conductive elements to communicate electrically with one another.

[0018] In an advantageous embodiment there is further provided an electrical contact monitoring arrangement that determines whether adequate axial force has been applied by the compression element so as to compress the resilient non-conductive element and thereby cause the first and second electrically conductive elements to communicate electrically with one another. The electrical contact monitoring arrangement additionally serves to determine whether adequate axial force has been applied by the compression element to urge the first and second electrically conductive elements into electrical communication with the base terminal. Preferably, at least one of said first and second electrically conductive elements is provided with a resilient contact element for communicating electrically with the other of the first and second electrically conductive elements.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] Comprehension of the invention is facilitated by reading the following detailed description in conjunction with the annexed drawings, in which:

[0020] FIG. **1***a* depicts a physical infrastructure capacity management system & integrated cabinet architecture according to one embodiment of the present invention;

[0021] FIG. **1***b* depicts a variant of the system architecture for an integrated cabinet, wherein one of the functional modules also serves as the intelligent cabinet hub;

[0022] FIG. **1***c* depicts yet another variant showing a wireless Ethernet network uplink to save data center switch ports;

[0023] FIG. **2***a* depicts a graphical representation of a data center layout;

[0024] FIG. **2***b* depicts a magnified excerpt of the data center layout;

[0025] FIG. **3***a* depicts a server installation process, facilitated and enforced by Physical Infrastructure Management (PIM) software and by the integrated cabinet;

[0026] FIG. **3***b* sets forth the legends for the PIM software graphical user interface symbols;

[0027] FIG. **4***a* depicts an integrated cabinet intelligent door arrangement according to the invention;

[0028] FIG. **4***b* depicts details of the intelligent door connector and of the temperature, and optionally humidity, sensor boards;

[0029] FIG. **5***a* depicts a physical structural representation of one embodiment of the integrated cabinet;

[0030] FIG. **5***b* depicts an excerpted portion of FIG. **5***a* that has been magnified to show greater detail;

[0031] FIG. **6** depicts a connected series of eight data center integrated cabinets;

[0032] FIG. **7** depicts an alternative connection configuration for a series of eight integrated cabinets;

[0033] FIG. **8** depicts a prior art connection of disparate functional modules as implemented within a physical infrastructure management system;

[0034] FIG. **9** is a graphical representation that illustrates resource savings that are achieved with the use of a physical infrastructure management system according to the present invention;

[0035] FIG. **10** depicts a simplified representation of an integrated cabinet equipped with a ground bond sensor;

[0036] FIG. **11***a* depicts a specific illustrative embodiment of the invention;

[0037] FIG. **11***b* depicts two principal parts of the invention represented in FIG. **11***a*; and

[0038] FIG. **12** depicts a schematic diagram of a circuit that is included within the hub for processing ground bond sensor signals.

DETAILED DESCRIPTION

[0039] FIG. **1***a* depicts a physical infrastructure capacity management system & integrated cabinet architecture according to one embodiment of the present invention. It contains top level data center network management software **110**, such as IBM Tivoli, Physical Infrastructure Management (PIM) software **115**, and a physical intelligent cabinet (enclosure not shown), the cabinet containing an integrated intelligent cabinet hub **120** and a collection of functional modules: A power module which is a block representing a modular power outlet unit **121**; an intelligent physical layer management module (IPLM) **122**, an example of which appears in Panduit's current PViQ product line; an environmental sensors module **123**, wherein examples of sensed parameters include temperature, humidity, air flow, differential pressure, vibration, and ambient light level, and automated temperature measurements can provide data to PIM software to simplify computational fluid dynamic (CFD) analysis of data center facilities; an asset tracking or asset location module **124**; a cabinet security module **125** for determination of cabinet door position and lock status, the cabinet security module **125** may also include a credential reader or a security camera link; display and beacon modules which are in a variety of user interface modules **126**; and a ground bond sensor and electrostatic discharge (ESD) policy enforcement module **127**.

[0040] FIG. **1***a* shows all of these modules **121-127** connected to integrated intelligent cabinet hub **120** through a serial data sub-network **130**. In this embodiment, the sub-network may employ an RS485 physical topology or other serial data sub-network, as shown.

[0041] While the serial data sub-network **130** preferably resides within a single integrated cabinet, designated generally as **135**, it may also span multiple cabinets (not shown). In this specific illustrative embodiment of the invention, the RS485 subnet includes additional power conductors, for example 12VDC, so that each module can operate from a single power supply (not shown) contained as part of the hub. The figure implies the presence of these additional power conductors, but does not show them explicitly. The multiplicity of sub-network conductors may take the form of multi-conductor cables (not shown), or alternately, a physical backplane (not shown) that accepts plug-in functional modules.

[0042] The function modules **121-127** communicate with integrated intelligent cabinet hub **120** via a communications link **131**. In some embodiments of the invention, there is provided an optional redundant communications link **132**.

[0043] Integrated intelligent cabinet hub **120** communicates upward in the diagram through an Ethernet connection **140** to Physical Infrastructure Management (PIM) software **115**. Other connection protocols can be used in the practice of the invention. PIM software **115** provides data aggregation, visualization, capacity planning functionality, and issuance of alerts to physical infrastructure issues that can potentially affect information technology uptime.

[0044] Integrated intelligent cabinet hub **120** contains in some embodiments of the invention multiple communication ports (not shown) in order to allow daisy chaining of hubs. This feature reduces the number of data center switch ports (not shown) that would be required to support the physical infrastructure capacity management system to less than one

per cabinet. Ports placed on the front of the cabinet hub may be offset from the front of the cabinet.

[0045] Some embodiments of the present invention comprise PIM software **115** that uses its functionality to process and consolidate information for further use by top-level data center network management software, such as IBM Tivoli **110**, HP OpenView, Microsoft System Center, or the like.

[0046] The collection of functional modules **121-127**, the integrated intelligent cabinet hub **120**, and the physical cabinet (not shown) constitute integrated cabinet **135**. The combination of the integrated cabinet appliances along with PIM software constitutes the physical infrastructure capacity management system. As stated, the physical infrastructure capacity management system optionally includes top level data center network management software **110**, which in this specific illustrative embodiment of the invention is IBM Tivoli.

[0047] FIG. **1***b* depicts a variant of the system architecture depicted in FIG. **1***a*, for an integrated cabinet. Elements of structure that have previously been discussed are similarly designated. In this embodiment, one of the functional modules, specifically power module **121**, also serves as part of an overall intelligent cabinet hub **150**. More specifically, overall intelligent cabinet hub **150** constitutes a cabinet hub and power supply functionality combined within a single appliance. In this embodiment, power module **121** performs the dual roles of a power outlet unit and of a hub. Although the figure shows a specific embodiment wherein power module **121** fulfills dual roles, in other embodiments of the invention, any of the other functional modules can incorporate the additional hub functionality.

[0048] FIG. **1***c* conveys yet another embodiment of the invention that is provided with a wireless Ethernet network uplink **155**. The use of wireless Ethernet network uplink **155** serves to reduce the number of otherwise required data center switch ports (not shown). Elements of structure that have previously been discussed are similarly designated. This figure also shows an alternate serial data subnet topology, consisting of multiple sections. In addition to the foregoing, the topology represented in this figure reduces the number of otherwise required module connections, and increases system reliability. Moreover, the particular subnet topology of this specific illustrative embodiment of the invention allows for detachment of intelligent doors (not shown) without affecting the communicability of other functional modules.

[0049] The specific illustrative embodiment of FIG. **1***c* is shown to have the function modules combined in respective sections. As shown, modular power outlet unit **121**, intelligent physical layer management module **122**, asset location module **124**, user interface modules **126**, and ground bond sensor and electrostatic discharge (ESD) policy enforcement module **127** constitute one section, that is generally designated as section **160**. Section **160** communicates with integrated intelligent cabinet hub **120** via a communications link **161**. There is optionally provided in this specific illustrative embodiment of the invention an optional redundant communications link **162**. Similarly, environmental sensors module **123** and cabinet security module **125** constitute a further section, identified as section **165**. Section **165** communicates with integrated intelligent cabinet hub **120** via a communications link **166**. There is optionally provided in this specific illustrative embodiment of the invention an optional redundant communications link **167**.

[0050] The coordination and synergy of the physical infrastructure capacity management system elements as hereinabove described affords the following advantages: 1) the network and sub-network connection topology achieves a reduction in IT switch port usage; 2) elimination of redundant power supplies; 3) reduction of module-borne Ethernet ports, associated computing power and memory requirements; 4) requires but a single PIM software-borne graphical user interface (GUI) in lieu of multiple independent software GUIs; 5) supports top-level data center network management software, by providing physical infrastructure management information. The integrated cabinet, together with PIM software, automates physical infrastructure data collection; 6) the system supports data center capacity planning; and 7) issuance of alerts relating to physical infrastructure issues that can potentially affect information technology uptime.

[0051] In one embodiment of the invention, the PIM system, such as Physical Infrastructure Management (PIM) software **115**, is combined with an integrated rack-unit-level RFID tracking system (not specifically designated) to enable the PIM system to acquire information quickly about the location and type of equipment installed.

[0052] FIG. **2***a* depicts graphically the layout of a data center **200**, and FIG. **2***b* represents a portion of the layout of data center **200**, the portion represented in this figure being enlarged to facilitate comprehension of these figures. In this embodiment, each of the grid squares, such as grid square **210**, represents a 2 foot by 2 foot square of floor space. Rows of server cabinets appear, most of which manifest the number 00, except for server cabinet icon **215** located at CX**120**, which shows the number 24. In this diagram, these numbers represent the number of servers contained within each of the cabinets. A row of switch cabinets **220** bisects the layout of data center **200**, dividing it into a left side **230**, and a right side **231** that is not shown in FIG. **2***b*.

[0053] FIG. **3***a* is a simplified schematic representation of that is useful in describing a process of installing one or more servers into the data center, which is not specifically designated in this figure. The installation is facilitated by, and is performed in conformance with, PIM software (not shown in this figure), and by the integrated intelligent cabinet hub (not shown in this figure). FIG. **3***b* depicts the legend for the PIM software graphical user interface symbols. The following description of the installation in accordance with the system of the present invention demonstrates a substantial reduction in the time and effort required to memorize and display moves, additions, or changes within a data center, as compared with prior art methods the involve the manual entry of data into spreadsheet files (not shown).

[0054] Referring to FIG. **3***a*, frame (**1**) shows a technician **310** inventorying a server asset **315** with the aid of an asset tag **320**. Asset tags that can be used in the various embodiments of the present invention include bar code and RFID (radio frequency identification) types of labels. By means of a unique code (not specifically designated) contained within the asset tag, the PIM system will associate the labeled equipment with associated data including, for example, model and serial numbers, purchase dates, warranty, physical size, nameplate power consumption, location, and other useful information. Technician **310** transports server asset **315** to an installation site while executing the required procedure for PIM system tracking of the asset location.

[0055] In FIG. **3***a* frame (**2**) the PIM system illuminates a beacon icon **327**, as well as a physical beacon **525** (see, FIGS. **5**A and **5**B) that directs technician **310** to a targeted physical cabinet **325** to conduct scheduled work. Physical cabinet **325**

is represented in the PIM system graphical view of data center **200** as server cabinet icon **215**, described above. Technician **310** presents an access credential (not shown) to a credential reader (not shown) mounted on or near physical cabinet **325**. In the practice of this embodiment of the invention, the credential reader is of a known type, and is capable of accepting any of several known types of identification information, such as a finger print, an access control identification card, key fob data, or any other type of credential information. If the PIM software contains a work order (not shown) for technician **310** that requires access to physical cabinet **325**, the system unlocks physical cabinet door **326**.

[0056] At any time, a remotely located PIM workstation makes available the physical cabinet status from within the data center view. PIM floor plan excerpt **340** appearing to the right of frame (**2**) provides visual indication of the status of physical cabinet **325** after physical cabinet door **326** is unlocked. The visual indication os status is made manifest with the use of icons that symbolize the following: Door CLOSED (icon **342**); Door UNLOCKED (icon **343**); and Beacon ON (icon **327**).

[0057] The PIM system at this point recognizes that 24 servers are installed/consumed within cabinet CX**120** (i.e., physical cabinet **325**, which is represented in PIM floor plan excerpt **340** as server cabinet icon **215**). Technician **310** is shown to present his or her access credential, and door **326** is unlocked.

[0058] In FIG. **3***a* frame (**3**), technician **310** opens physical cabinet door **326** and executes the scheduled work, such as the installation of a server (not shown) that is reflected in server asset icon **215**, blanking panel installation and removal, and patching activities. Such scheduled work may also include manually scanning all of the installed or removed assets' bar codes or RFID labels with a hand held scanner/reader (not shown) to record new location information. PIM floor plan excerpt **340** now shows the following: Door OPEN (icon **345**); Door UNLOCKED (icon **343**); and Beacon ON (icon **327**).

[0059] The PIM system at this point recognizes that 24 servers are installed/consumed within cabinet CX**120**. In this frame (**3***a*), the PIM floor plan excerpt **340** shows the current count for a cabinet that lacks an integrated RFID asset tracking module.

[0060] If physical cabinet **325** contains an integrated RU (rack unit) level RFID asset tracking module (not shown), the PIM system quickly absorbs the asset and location information, and then stores the corresponding data in the PIM's database (not shown). Frame (**3***a*) represents this scenario.

[0061] After correctly installing the server and executing all of the scheduled work, technician **310** closes physical cabinet door **326** as shown in FIG. **3***a* frame (**4**). PIM floor plan excerpt **340** depicts: Door CLOSED (icon **342**); Door UNLOCKED (icon **343**); and Beacon ON (icon **327**).

[0062] The PIM system at this point recognizes that 24 servers are installed/consumed within cabinet CX**120**. In this diagram, the excerpt shows the current count for a cabinet that lacks an integrated RFID asset tracking module.

[0063] FIG. **3***a* frame (**5**) illustrates the cabinet status after the system has locked physical cabinet door **326** and extinguished the beacon. This is represented in PIM floor plan excerpt **340**, which depicts: 1) Door CLOSED (icon **342**); 2) Door LOCKED (icon **344**); and 3) Beacon OFF (icon **328**).

[0064] In one embodiment, the PIM system recognizes that 24 servers are installed/consumed within cabinet CX**120**. In this diagram, the PIM floor plan excerpt **340** shows at server cabinet icon **215** that the current count for physical cabinet **325** lacks an integrated RFID asset tracking module. If the cabinet indeed lacks an integrated RFID asset tracking module, technician **310** must then upload the new asset location information into the PIM system manually. This may be accomplished with the data stored inside of a hand-held bar code scanner, a hand held RFID reader, or some other portable data medium, generally designated as handheld reader **311** (see, frame (**5***a*)).

[0065] FIG. **3***a* frame (**6**) represents the PIM's current recognition of 25 servers that are installed/consumed within cabinet CX**120**. In addition, the PIM software now displays an updated location tree. Thus, the PIM floor plan excerpt **340** in frame (**6**) conveys that all such associated views and the underlying data have been updated. It is to be noted that in accordance with the embodiment of FIG. **3***a*, the system arrives at the database content shown in frame (**6**) from two differing routes, depending upon the asset tracking method. When integrated cabinets having associated RU RFID modules are employed, the manual data entry step depicted in frame (**5***a*) is not required.

[0066] FIG. **3***b* depicts some of the software icons and structural elements that are employed in the specific illustrative embodiment of the invention. These include: icon **344** designating door locked; icon **343** designating door unlocked; icon **328** designating beacon OFF; icon **327** designating beacon ON; icon **342** designating door closed; icon **345** designating door open; icon **215** designating the server cabinet; icon **220** designating a switch cabinet; icon **351** designating power and maximum usage; PIM screen **352** designating the PIM screen; PIM report **353** designating the PIM report; and server asset **315** designating the physical tagged asset.

[0067] FIG. **4***a* depicts the integrated cabinet intelligent door system of the present invention. Elements of structure that have previously been discussed are similarly designated. As shown in this figure, physical cabinet door **326** is provided with a perforated door panel **410** that provides a suitable mounting location for temperature (and optionally humidity and pressure) sensors **415**. The door mounting location for sensors **415** is advantageously less cluttered with cabling, and provides safety from damage resulting from ongoing appliance relocation within physical cabinet **325** (not shown in this figure). In some embodiments of the invention, these sensors **415** are part of a containment/cooling/control system (not shown). In addition, commercially available electronic swing handle door locks with one or more integrated credential readers, shown as integrated door lock and credential reader **420**, are mounted on physical cabinet door **326** via standardized panel cutout dimensions (not specifically designated).

[0068] The use of physical cabinet door **326** as a venue for electronic devices presents the challenge of delivering serial data sub-network conductors **450** across the junction between physical cabinet **325** and perforated door panel **410** of physical cabinet door **326**. The door panel may incorporate in some a dual-hinged feature (not shown), that impedes the use of a cable loop solution at one of the hinges (not shown). In order to overcome this challenge, a plurality of contacts **455** is disposed at the top of physical cabinet door **326**, which contacts communicate electrically with contacts (not shown) that are attached to the cabinet body (not shown in this figure) upon closure of physical cabinet door **326**. These contacts may, in some embodiments, take the form of a conductor-to-

conductor interface (not shown), or of magnetic elements (not shown) that engage when physical cabinet door **326** is closed. Such an arrangement of magnetic elements effectively forms a corresponding plurality of transformers (not shown), that are suitable for both, signaling and power delivery.

[0069] The incorporation of one or more microprocessors **460** (see, FIG. **4***b*) (i.e., a programmable integrated circuit that runs algorithms) and serial communications (not shown in this figure) within these functional modules makes them self-identifying, self-addressing, and self-configurable. For example, a nonvolatile memory (not shown) within sensors **415** may store information indicative of a device type (e.g., temperature sensor); and a device address (e.g., a unique code such as a serial number).

[0070] In some embodiments of the invention the serial communications sub-network may also contain a daisy chain line, that is usable to determine the relative position of each of the module elements. For example, PViQ patch panels, available from Panduit Corp., use this methodology to deduce the relative position of each device. In one embodiment if the intelligent door temperature sensor of the present invention, the relative position information provides the spatial coordinates for the location of each sensor.

[0071] Automated collection of temperature data, especially over time, significantly simplifies and improves computational fluid dynamic (CFD) analysis of the data center facility. In accordance with the invention, the greater distribution of environmental measurement points with the data being collected continually, replaces the laborious prior art method of manual temperature data collection. This provides more thorough, timely, and current information, as well as visibility of variations over time. More accurate data increases confidence in the calculation of the maximum thermal capacity of a data center. Such increased confidence more accurately identifies current operational margins, as well as the trigger points for build-out of new data center facilities, including the provision of data for cooling, power, connectivity, device location, and the amount of space available.

[0072] FIG. **4***b* shows details of a module **457** that bears a serial sub-network and power connector **455**. Module **457** further includes individual sub-network and power circuits contacts **458** for physical cabinet door **326**. There is additionally shown in this figure a module **459** formed of a printed circuit board **456** that bears, in this embodiment, temperature sensors **415** and microprocessor **460**. This module **459** additionally is provided with serial sub-network and power connectors **465** and **466**.

[0073] FIG. **5***a* depicts a physical, structural view of one embodiment of physical cabinet **325** and physical cabinet door **326**. FIG. **5***b* depicts an excerpted portion of the embodiment of FIG. **5***a*, specifically of physical cabinet **325**, that has been magnified to show greater detail. In these figures, elements of structure that have previously been discussed or that bear analogous correspondence are similarly designated. As shown in these figures, integrated intelligent cabinet hub **120** resides within a space provided at the top of physical cabinet **325**. In other embodiments, however, integrated intelligent cabinet hub **120** is installed into one or more of the horizontal or vertical rack unit (RU) slots (not specifically designated).

[0074] A first portion of the asset management functional module, specifically RU-level RFID reader **515**, assumes a dual role as integrated intelligent cabinet hub **120**. A second portion of the asset management functional module, the RU-level RFID asset tag reader strip **520**, mounts vertically alongside assets deployed inside the cabinet. RU-level RFID asset tag reader strip **520** is shown to be connected in this embodiment to a reader coaxial port **521**. The asset tag reader strip facilitates communication with tags placed upon the assets, such as intelligent physical layer management modules **122**, which in some embodiments are PViQ patch panels, available from Panduit Corp., that are installed in the racks. In addition, each such PViQ patch panel in this embodiment is provided with a respective asset tag **320**.

[0075] Physical cabinet door **326**, which in this embodiment incorporates a plurality of environmental monitoring and security functions, is shown to be in the open position, within the left portion of FIG. **5***a*. A collection of Power Outlet Units (POUs) **536**, with associated power metering functionality, occupy vertical columns on the right and left sides of the cabinet body. As previously discussed, the opening of physical cabinet door **326** will result in the continued illumination of physical beacon **525**. As above noted, physical beacon **525** is illuminated concurrently with the display of beacon icon **327**, and since it is located on the top of the cabinet body in this embodiment of the invention, it can be illuminated prior to the opening of physical cabinet door **326** to direct technician **310** (not shown in this figure) to the particular cabinet (e.g., physical cabinet **325**) that requires servicing.

[0076] In this specific illustrative embodiment of the invention, Intelligent Physical Layer Management (IPLM) modules **122**, labeled in the figure as "PViQ EMs (or, Expansion Modules)," reside at the uppermost rack positions in the figure. These modules provide managed patching functionality within physical cabinet **325**.

[0077] The functional modules each connect to integrated intelligent cabinet hub **120** via one or more sections of serial data sub-network **130**, as previously described. In FIGS. **5** through **8**, squares labeled with "R" (generally shown as RS485 connection points **530**) correspond to RS485 connection points (or another communication connection for the serial data sub-network). The squares that are labeled with "E" designate respective Ethernet connection points **535**. RU-level RFID asset tag reader strip **520** communicates with reader coaxial port **521** of RU level RFID reader **515** through a coaxial cable (shown, but not specifically designated). The coaxial borne communications include separable RF messaging, in addition to serial data sub-network messaging.

[0078] Referring again to FIG. **5***a*, the physical cabinet **325** communicates through an Ethernet channel **540** to a PIM server **545**. The depicted Ethernet cloud **550** abstracts a collection of switches, routers, structured cabling, and other required network elements, which are not specifically shown for sake of clarity and to avoid immaterial detail. A PIM workstation, database **555**, and PIM server **545** constitute other elements of the physical infrastructure capacity management system. Such physical infrastructure is available at a PIM workstation **560**.

[0079] FIG. **6** depicts a simplified schematic representation of a connected series of eight data center integrated cabinets **611**, **612**, **613**, . . . **618**. The integrated cabinet hub (not specifically designated) contained by first physical data center integrated cabinet **611** connects to the other integrated hubs through the serial data sub-network **625**, optionally including, in this specific illustrative embodiment of the invention, dedicated daisy chain and power conductors as earlier described. The series of eight physical data center integrated cabinet **611**, **612**, **613**, . . . **618** then requires just a

single power supply **630** to operate all of the associated management functional modules and hubs. The power supply connection may mate with a power source available within or near first physical data center integrated cabinet **611**. It is noted that the depicted power supply **630** provides operating energy only for the physical infrastructure management functional modules and hubs, and not for the relatively heavy server and switch loads that derive operating power from the Power Outlet Units (POUs) **536** shown in FIG. **5***a*. Those heavy loads require dedicated, often redundant, power feeds (not shown) through the load outlet connectors of Power Outlet Units (POUs) **536**.

[0080] FIG. **7** depicts an alternative connection configuration for a series of eight physical data center integrated cabinet **611**, **612**, **613**, . . . **618**. Elements of structure that have previously been discussed are similarly designated. In this case, a dedicated plurality of coaxial connectors **710** on the first cabinet connects with each of the other cabinet coaxial connectors through a coaxial cable, resulting in a "star" connection scheme. The coaxial-borne communications may again include separable RF messaging, in addition to serial data sub-network messaging.

[0081] The specific illustrative embodiments of the invention shown in FIGS. **6** and **7** offer a limited sample of connection topologies. It is to be understood that in the practice of the invention, any of these connection topologies can be employed, including a combination of these and other topologies.

[0082] In practice, some of the functional modules are connected to the Ethernet network directly, bypassing the serial data sub-network. A practicable embodiment of the integrated cabinet hub bears a multiplicity of Ethernet connection points to accommodate this circumstance. In some embodiments, the hub incorporates Ethernet switch functionality in support of functional modules equipped with Ethernet communication ports. The hub's multiple Ethernet ports reduce the relatively costly cloud-borne (network) Ethernet switch ports to less than one per cabinet. FIGS. **5***a* and **5***b* show the hub's multiple Ethernet ports most explicitly. The Ethernet ports have been omitted in some of the figures for the sake of clarity in presenting the preferred embodiments.

[0083] FIG. **8** illustrates a prior art connection of disparate functional modules (not shown in this figure) as implemented within a physical infrastructure management system, and using a disintegrated cabinet concept. These functional modules include: 1) power metering; 2) IPLM (Intelligent Physical Layer Management); 3) environmental monitoring; 4) asset management; and security.

[0084] As shown, FIG. **8** represents the upper portions of eight physical cabinets **811** . . . **818**, without an integrated cabinet hub. There are shown for the eight physical cabinets **811** . . . **818** respectively associated Ethernet connection points that generally are designated **821** . . . **828**. The Ethernet connection points in this embodiment constitute a portion of respectively associated patch panels **801** . . . **808**, that are suitable for the connection of internal Ethernet patch cords (not shown) between internal functional module appliances (not shown) and an Ethernet switch, represented by Ethernet Cloud **550**. It is noted that such necessary Ethernet switches may, in respective embodiments of the invention, reside externally or internally with respect to the eight physical cabinets **811** . . . **818**.

[0085] Each of the eight physical cabinets **811** . . . **818** requires separate Ethernet ports for power metering, IPLM, environmental monitoring, asset management, and security. All of these except for the power metering modules also require dedicated power supplies, since power metering modules often derive operating power from the power feeds (not shown) that primarily energize their associated heavy loads. A disintegrated physical infrastructure management system will require separate servers, illustratively including: a power metering server **830**; an IPLM server **831**; an environmental server **832**; an asset management server **833**; and a security server **834**.

[0086] In addition, the disintegrated physical infrastructure management system will require separate databases, such as databases **840** and **841**. In such embodiments, separate graphical user interfaces (not shown) are available through user workstation **560**.

[0087] FIG. **9** is a graphical illustration of resource savings that are enabled by methods using a physical infrastructure management system incorporating features described herein. The vertical axis of the illustration shows the physical infrastructure capacity for an enterprise, and the horizontal axis shows time. In this case, the physical infrastructure capacity is a summary term combining a number of factors such as physical space, thermal capacity, power availability, connectivity, and rack space. The effective physical infrastructure capacity can be considered as being bounded by the "most limiting" of these factors. For example, if there is plenty of space and power for expansion, but not enough cooling available for expansion, thermal capacity is the most liming physical infrastructure factor.

[0088] A first plot **10** illustrates the measured consumption of physical infrastructure resources under a prior art method of determining capacity expansion. A second plot **12** illustrates the measured consumption of physical infrastructure resources using a method according to the present invention.

[0089] A number of horizontal lines are used to indicate the physical infrastructure capacity over time. The horizontal lines **14** and **16** represent a guardbanded initial amount of physical infrastructure capacity in a data center. The horizontal lines **18** and **20** indicate a guardbanded amount of physical infrastructure capacity that results from expanding the data center. The horizontal lines **22** and **24** represent a guardbanded physical infrastructure capacity that results from building a new data center following the expansion. Systems of the present invention allow for narrower guardbands, because decisions to expand can be made at a more appropriate time.

[0090] An arrow **26** represents a time at which a decision is made that an expansion of physical infrastructure capacity will be needed for an existing system. This decision is made due to the understanding of the physical infrastructure needs at that time, which under known systems is flawed due to infrequent and inaccurate measurement of current capacity, consumption, and needs. For example, early in the graph of FIG. **9**, plot **10** has a steeper slope than plot **12**, which presents more accurate information regarding the consumed physical infrastructure capacity. In prior art systems, the decision to expand the data center is being made too early, and the needed additional capacity appears to be much larger than the actual needs of the enterprise.

[0091] As a result, in this illustrated scenario, under a prior art approach, the data center is expanded too largely, too quickly. Thus, greater-than-necessary resources (capital expenditures, or CAPEX) are used earlier than needed, resulting in the misallocation of the capital expenditures.

[0092] Similarly, arrow **28** represents a time at which a decision is made that a new data center will be needed under a prior art decision-making system. Once again, under the prior art system, this decision is made too early in the life of the enterprise, in comparison to the actual amount of physical infrastructure capacity needed, resulting in a capital expenditure misallocation. In both cases, the CAPEX savings resulting from a more correctly timed decision are indicated on the graph.

[0093] In addition to resulting in unnecessary capital expenditures, an incorrect understanding of the environmental data in a data center can result in operational expenditures that grow at an unnecessarily fast rate. For example, referring again to FIG. **9**, the fast growth in apparently used physical infrastructure capacity under the prior art plot **10** may reflect an overcooling scenario, which may have been the result of faulty temperature readings, which may have been taken infrequently. As a result, an ongoing operational expenditure (OPEX) to cool the data center to a temperature that is unnecessarily low may have resulted in a substantial waste of money for the enterprise. Embodiments of the present invention will lead to proper allocation of operational expenses, leading to the OPEX savings indicated in FIG. **9**.

[0094] Systems according to embodiments of the present invention enable accurate measurements to be aggregated and presented to a user in the form of actionable information, allowing the user to make resource planning decisions more accurately and efficiently. Examples of decisions that can be facilitated under the present invention include: 1) Allocation of the proper amount of cooling resources; 2) Allocation of physical space to need the computational and connectivity requirements of the enterprise; 3) Determining whether to expand an existing datacenter or to build a new one; 4) The provision of an appropriate amount of power over the life cycle of a datacenter; 5) Identification of the limiting resource in an enterprises' physical infrastructure capacity and an understanding of the amount of that resource that needs to be added (for example, switching capacity may be the limiting factor, such that more switches should be added but not necessarily more rack unit (RU) space); and 6) Identification of locations within a data center that meet requirements for new hardware (such requirements may include connectivity type and speed.

[0095] Sensing of grounding and bonding may also be incorporated into some embodiments of the present invention. Grounding and bonding of equipment and infrastructure within data centers fulfills at least 2 significant needs: (a) safety of users and maintenance personnel; and (b) increased reliability of sensitive electronic appliances through mitigation of electrostatic discharge potentials carried upon the bodies of users and maintenance personnel.

[0096] While existing ground bond schemes have the capability to fulfill these safety and ESD mitigation needs, they offer no method of verifying or monitoring the electrical connection and bonding of the ground conductors to the Mesh Common Bonding Network (MCBN). As a result, a data center's infrastructure may completely lack the required grounding and bonding, and owners, users, and maintenance personnel may remain completely unaware of this status with its associated risks. A system capable of monitoring the ground bond status of the infrastructure's ground connections, and capable of notifying appropriate personnel in the event of a missing or loose connection, therefore offers a significant security benefit to these stakeholders.

[0097] FIG. **10** depicts a simplified representation of physical cabinet **325** equipped with a ground bond sensor **1010**. Elements of structure that have previously been discussed are similarly designated. Physical cabinet **325** undergoes ground bonding to mesh common bonding network (MCBN) **1020** through ground bond sensor **1010** that, in turn, connects to a dedicated ground bond sensor port **1030** on integrated cabinet hub **120**. Integrated intelligent cabinet hub **120**, in combination with ground bond sensor **1010**, verifies the presence of a ground connection to the cabinet, and verifies that the installer (not shown) has bonded the ground connection to mesh common bonding network (MCBN) **1020**.

[0098] FIG. **11***a* depicts a specific illustrative embodiment of the invention of a ground bond sensor **1010**. FIG. **11***b* illustrates that ground bond sensor **1010** consists of two main portions, specifically: 1) A Ground Sensor, for example, a ground terminal lug **1041** with a heavy-gauge ground conductor **1043** leading to mesh common bonding network (MCBN) **1020** (not shown in this figure), plus a smaller-gauge ground sense pilot wire **1045** leading to the hub's dedicated ground bond sensor port **1030** (not shown in this figure); and 2) A donut or flat-washer shaped Bonding Sensor **1050**, with an isolated, normally open contact (not shown), and signal wires **1051** that lead to the hub's dedicated ground bond sensor port **1030** (not shown in this figure). Bonding Sensor **1050** provides an electrically isolated contact closure indication that the installer has tightened the ground fastener, that it remains snug, and that the fastener's clamping force exceeds a minimum specified value.

[0099] An isolated, normally open contact (not shown) prevents the sensor function from easily being defeated by merely tying the appropriate gateway sensor port terminals to ground. This form of contact also enables connection of multiple signals together, either physically with wire, or logically through electronic processor algorithms.

[0100] Ground Bond Sensor arrangement depicted in FIG. **11***a* consists of two one-sided printed circuit boards (PCBs) **1061** and **1062**, respectively, separated by a spring element **1065** in the form of a stiff wave washer or O-ring, and sandwiched between two metallic flat washers **1068** and **1069**. In this embodiment, metallic washer **1068** is a metallic stepped washer that is urged toward, and is stopped against, metallic washer **1069** upon the tightening of fastener **1070**, which in this embodiment is a #10-32 screw. Fastener **1070** engages threadedly with a threaded hole in (not shown), or nut on (not specifically designated), cabinet surface **1075**.

[0101] One-sided printed circuit boards (PCBs) **1061** and **1062** are, in this specific illustrative embodiment of the invention, somewhat donut shaped. Optional spring contacts mounted to the PCBs, such as spring contact **1073**, mate with etched pads (not shown) on the opposite PCB. Alternatively, a simple disc will bridge the two PCBs together upon application of sufficient torque to fastener **1070**. A plastic cover ring **1071** captivates the sensor parts such that the cover ring suffers no compression during application of torque to the ground fastener. A second spring element, a stiff wave washer or O-ring, provides enough reactive force to preclude contact closure by merely tightening the screw by hand. This assures that the installer has used a tool to apply torque, or otherwise bond, the connection. The top washer has a stepped geometry in order to provide a solid stop against the bottom metal washer during the application of torque to the screw. This limits the compression of the spring element and the PCB contacts to tolerable levels. In the case where a simple disc

bridges the two PCBs together, the disc thickness limits the compression of the spring element.

[0102] Ring terminal **1041**, or ground terminal lug, preferably resides directly adjacent to the grounded cabinet surface **1075**, the cabinet surface being provided with a conductive pad (not shown) (for example, a copper pad), free of paint or other insulating materials. This stack up maximizes the conduction surface area of the connection between the MCBN and the cabinet chassis. In other embodiments, the field application of the present sensor can include a paint-piercing tooth washer, and optionally a tri-lobular screw to cut through paint coated threads, with satisfactory grounding results. The screw will incorporate, in some embodiments, a binding type head or other locking mechanisms, such as various types of lock washers (not shown). There is optionally provided in this embodiment an internal tooth metallic star washer (not specifically designated) to enhance engagement between ring terminal **1041** and cabinet surface **1075**.

[0103] FIG. **11***c* illustrates an embodiment of a ground bond sensor **1080** integrated with a ground bond wire **1081**. This embodiment reduces the number of parts to handle during installation. Although not shown explicitly, the wires that egress the right side of the assembly break out to their associated hub port and MCBN destinations. The embodiment optionally incorporates an indicator LED **1083**, and a screw captivation feature (not shown).

[0104] It is noted that other bonded ground connections, such as directly at the MCBN, can also utilize the ground bond sensor. Preferred embodiments require that fastener schemes employ a headed screw or bolt under tensile load, a torqued nut, or a similar application of compressive force to the Sensor.

[0105] FIG. **12** is a schematic representation of a specific illustrative embodiment of the invention. This circuitry, which in some embodiments is included within the hub, processes the ground bond sensor signals. The hub dedicated ground bond sensor port circuit contains a signal reference, shown as the earth ground symbol, representing an equal potential connection from the hub to: 1) the cabinet chassis ground, by means of the hub's chassis mounting fasteners; or 2) the ground wire, taken from an AC power feed to the cabinet; or 3) the MCBN.

[0106] The circuitry functions as follows. The ground sense pilot wire connects the SLEEVE terminal of connector J**11**. With the ground lug of FIG. **11***a* or **11***b* connected to the cabinet chassis, and the sensor cable (ground sense pilot wire) plugged into the hub's dedicated sensor port, signal voltage at GND_DET**1** goes to 0V. Low pass filtering and transient protection protect this node from noise and other energetic transients. If the cabinet lacks a ground lug, or if the installer has not plugged the sensor cable into the hub sensor port (J**11**), the GND_DET**1** signal level goes to 3.3V. Although redacted for brevity, GND_DET**1** connects to a microprocessor input (not shown), such as an input of Microchip part number PIC24FJ256GA110-IPF. Programmatic algorithms contained within the microprocessor memory report the status of this signal upstream to the PIM Server to notify personnel responsible for the data center.

[0107] The bonding sensor signal wires connect to the TIP and RING terminals of J**11**. An open contact, signifying UNBONDED sensor status, causes the GND_DET**2** signal voltage to remain low. A closed contact, signifying BONDED sensor status, causes the GND_DET**2** signal voltage to go high. Although redacted for brevity, GND_DET**2** connects to a microprocessor input (not shown), such as an input of microchip part number PIC24FJ256GA110-IPF. Programmatic algorithms contained within the microprocessor memory report the status of this signal upstream to the PIM Server to notify personnel responsible for the data center.

[0108] Note that with a minor change to the hub circuitry, the bond sensor (or integrated ground bond sensor) could incorporate a visible LED across its normally open contacts to visually indicate, at the sensor, a loose or disconnected termination. In this case the identification and remediation of the incorrect connection becomes much less troublesome and time consuming, especially in large data centers. The capability of this system to report automatically ground bond status to the PIM server, to notify appropriate personnel, also eases maintenance and increases reliability of the data center's physical infrastructure.

[0109] In yet a further embodiment of the ground bond sensor, the hub circuitry incorporates a digital communication stream between the sensor and the hub. In this embodiment, the sensor incorporates an intelligent device such as Microchip PIC10F283 or Maxim/Dallas DS2401X1. These intelligent devices contain, in some embodiments, a code that uniquely identifies each sensor, and further includes the capability to memorize data communicated through the serial digital communications. A difference in the information communicated from these sensor devices indicates the status of the sensor. In a specific illustrative embodiment of the invention, the set of states is as follows: 1) No communications=sensor not present or unplugged; 2) 1111 1111=sensor plugged in and bonded; and 3) 0101 0101=sensor plugged in and unbounded.

[0110] This embodiment carries the further advantage that each sensor can uniquely identify itself when deployed with a plurality of such sensors, within a multi-drop serial data subnetwork.

[0111] Some embodiments of the present invention comprise the following features: a data center physical infrastructure capacity management system including an intelligent/integrated server cabinet provisioned with a plurality of sensors (at least one sensor) or actuators, a means of data communication from sensors to one or more datacenter system management databases, and a datacenter system management database for receiving communications from the cabinets and for storing the received information.

[0112] The cabinet periodically providing the datacenter system management database with ongoing environmental data representative of various ongoing states of the data center's physical infrastructure.

[0113] The data center physical infrastructure capacity management system also includes data processing means to determine algorithmically human or automated intervention to the data center's physical infrastructure, the intervention taking the form of: 1) moves, additions, or changes to the physical infrastructure; 2) moves, additions, or changes to the representative underlying datacenter system management database; 3) alerts to IT personnel; and 4) at least one human interface, enabling human interaction with the data center management system.

[0114] Although the invention has been described in terms of specific embodiments and applications, persons skilled in the art can, in light of this teaching, generate additional embodiments without exceeding the scope or departing from the spirit of the invention herein described and claimed. Accordingly, it is to be understood that the drawing and

description in this disclosure are proffered to facilitate comprehension of the invention, and should not be construed to limit the scope thereof.

1. A data center physical infrastructure capacity management system, the system being managed by IT personnel, the system comprising:

a server cabinet having rack spaces and a sensor;

a data communication arrangement for propagating communications signals from the sensor to a management database that receives information from the communications signals, the received information being stored;

a data processor for determining algorithmically the need for intervention to the data center physical infrastructure, the intervention taking the form of:

changes to the physical infrastructure;

alerts to IT personnel; and

a human interface for enabling human interaction with the data center management system.

2. The data center physical infrastructure capacity management system of claim **1**, wherein the received information corresponds to environmental data.

3. The data center physical infrastructure capacity management system of claim **1**, wherein the intervention determined by said data processor comprises a selectable one of human and automated intervention.

4. The data center physical infrastructure capacity management system of claim **1**, wherein the intervention determined by said data processor takes the additional form of changes to the representative underlying data center system management database.

5. The data center physical infrastructure capacity management system of claim **1**, wherein said human interface comprises a graphical user interface for displaying icons representative of predetermined condition states of the data center.

6. The data center physical infrastructure capacity management system of claim **1**, wherein said data processor comprises a computer, and the algorithmic determination of the need for intervention is responsive to any combination of:

temperature data;

humidity data;

a sensor address;

a device serial number;

the adequacy of a system ground connection; and

the number of occupied rack spaces.

7. A cabinet for holding removable electronic assets, the cabinet comprising:

a cabinet body having a plurality of rack spaces, each for accommodating one of the removable electronic assets;

a plurality of identifier tags, each attached to a respectively associated one of the removable electronic assets;

an identifier tag reader installed on said cabinet body for communicating with at least one of said plurality of identifier tags and providing a tag reader electrical signal responsive to the communication with the at least one of said plurality of identifier tags;

a cabinet door movably attached to said cabinet body; and

a door sensor for providing an electrical signal responsive to closed, open, locked, and unlocked states of said cabinet door.

8. The cabinet of claim **7**, wherein there is further provided a data output for providing data responsive to the tag reader electrical signal.

9. The cabinet of claim **7**, wherein there is further provided a database for storing asset information responsive to the presence of the removable electronic assets in respective ones of the rack spaces, the asset information being obtained from the tag reader electrical signal derived from said identifier tag reader.

10. The cabinet of claim **9**, wherein said identifier tag reader comprises an elongated antenna element affixed to said cabinet body and extending proximal to a plurality of the rack spaces.

11. The cabinet of claim **9**, wherein said database is maintained in a remote server.

12. The cabinet of claim **9**, wherein there is further provided an integrated cabinet hub disposed in said server cabinet for coordinating respective data signals from any combination of:

a power monitoring arrangement;

a physical layer management system;

an environmental control system;

an asset tracking system;

a grounding monitoring system; and

a security system.

13. The cabinet of claim **12**, wherein there is provided a wireless communication arrangement for delivering data from said integrated cabinet hub to a physical infrastructure management system.

14. The cabinet of claim **7**, wherein there is further provided a monitoring arrangement, said monitoring arrangement having a graphical user interface for displaying icons representative of predetermined condition states of the cabinet.

15. The cabinet of claim **7**, wherein there are further provided:

an environmental sensor installed on said cabinet door; and

an electrical contact arrangement having a cabinet door portion and a cabinet body portion for conducting signals from said environmental sensor containing environmental information to said cabinet body.

16. The cabinet of claim **7**, wherein there is further provided a credentials monitoring arrangement for controlling the state of said cabinet door.

17. A secure contact arrangement comprising:

a base terminal formed of electrically conductive material;

first and second electrically conductive elements;

a resilient non-conductive element interposed between said first and second electrically conductive elements; and

a compression element for applying an axial force through said first electrically conductive element, said resilient non-conductive element, said second electrically conductive element, and said base terminal, whereby a compression force applied by said compression element compresses said resilient non-conductive element to cause said first and second electrically conductive elements to communicate electrically with one another.

18. The secure contact arrangement of claim **17**, wherein there is further provided an electrical contact monitoring

arrangement for determining whether adequate axial force has been applied by said compression element to compress said resilient non-conductive element and thereby cause said first and second electrically conductive elements to communicate electrically with one another.

19. The secure contact arrangement of claim **18**, wherein said electrical contact monitoring arrangement additionally serves to determine whether adequate axial force has been applied by said compression element to urge said first and second electrically conductive elements into electrical communication with said base terminal.

20. The secure contact arrangement of claim **17**, wherein at least one of said first and second electrically conductive elements is provided with a resilient contact element for communicating electrically with the other of said first and second electrically conductive elements.

* * * * *