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(54) SYSTEM AND METHOD FOR AGGREGATING INFORMATION TO DETERMINE A USER'S LOCATION

(76) Inventors: **Anand Naga Babu**, Peoria, IL (US); **Abraham S. Heifets**, Menlo Park, CA (US); **Adam Krauszer**, Ithaca, NY (US); **Roy Paterson**, Austin, TX (US); **Brian Lee White Eagle**, Austin, TX (US)

Correspondence Address:
Greg Goshorn, P.C.
9600 Escarpment
auite 745-9
AUSTIN, TX 78749 (US)

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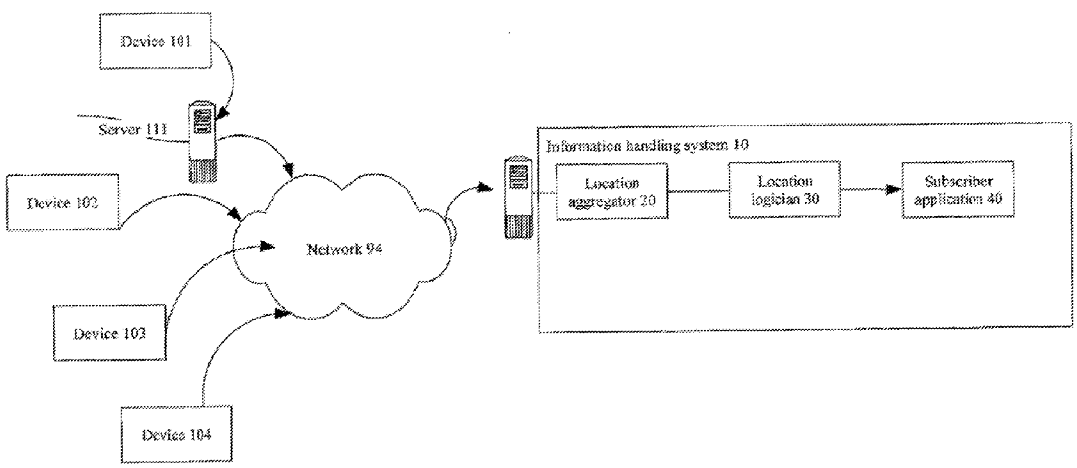
(57) **ABSTRACT**

Provided is a system and method that acquires and aggregates information to determine the location of a user. Information from multiple sources is collected and evaluated. Location sources include mobile electronic devices such as mobile telephones, cell phones, hand-held computers, personal digital assistants, pagers, Global Positioning System (GPS) devices, and other pervasive computing devices. Satellite-based or network-based positioning technologies make ti possible to determine the geographic location of these wireless electronic devices and their coresponding user. Location sources also include computer-based models, schedules or calendars that gave a particular user's expected location depending on the date and time. Provided is a method for aggregating information to determine a user's location. Also provided is a system for executing the claimed method. Also provided is a service for providing the claimed method.



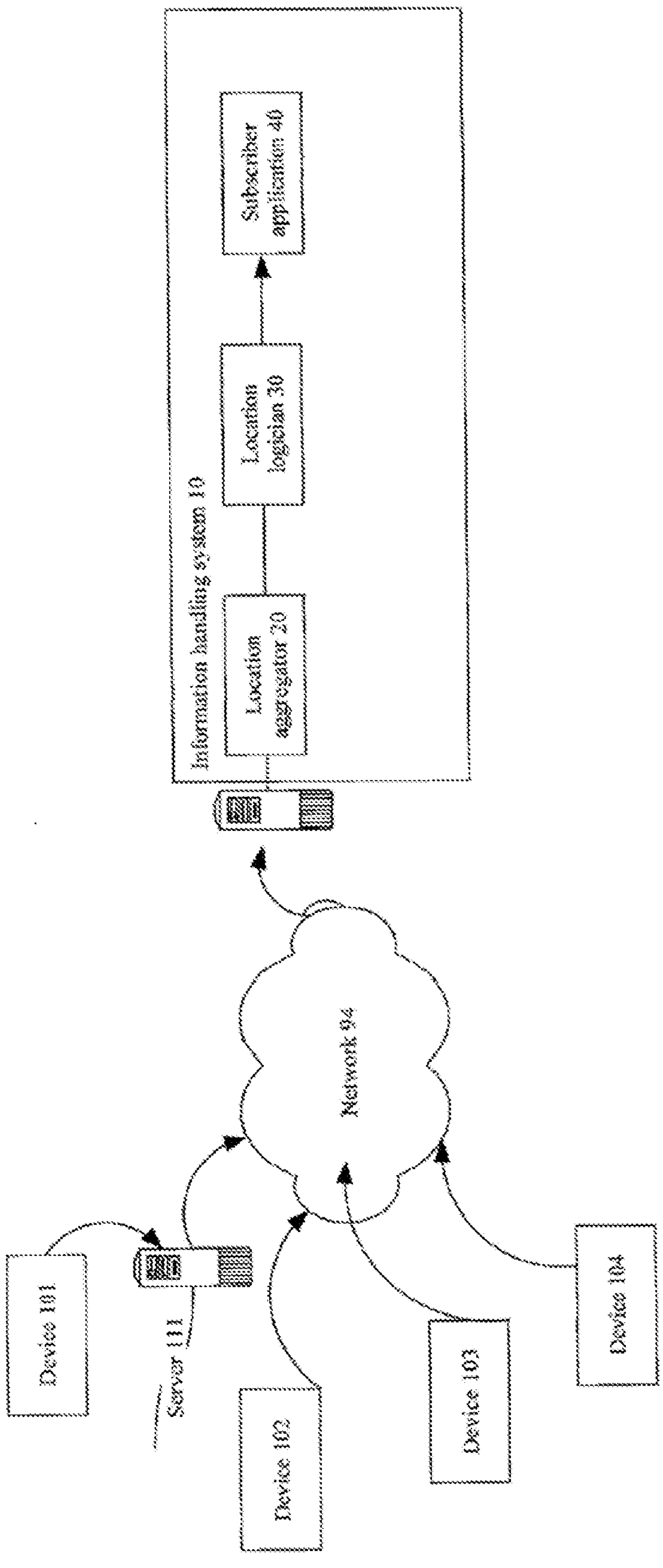

Information handling system 10
Location aggregator 20
Location logician 30
Subscriber application 40
Network 94
Device 101
Server 111
Device 102
Device 103
Device 104

Figure 1

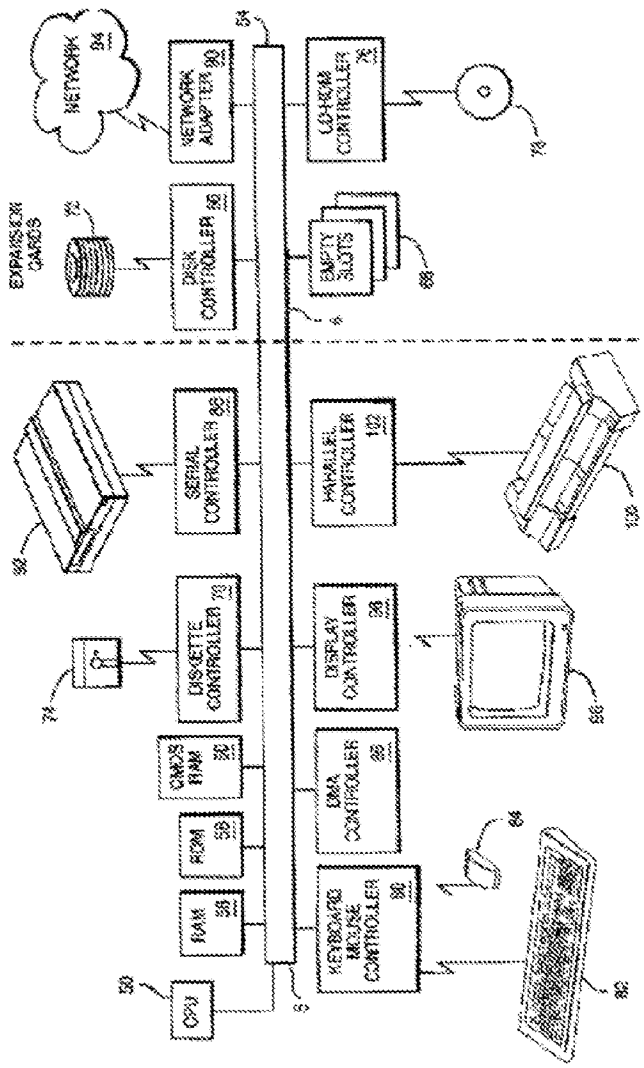

NETWORK
NETWORK ADAPTER
CD-ROM CONTROLLER
EXPANSION CARDS
DISK CONTROLLER
EMPTY SLOTS
SERIAL CONTROLLER
PARALLEL CONTROLLER
DISKETTE CONTROLLER
DISPLAY CONTROLLER
CMOS RAM
DMA CONTROLLER
ROM
RAM
KEYBOARD MOUSE CONTROLLER
CPU

Figure 2

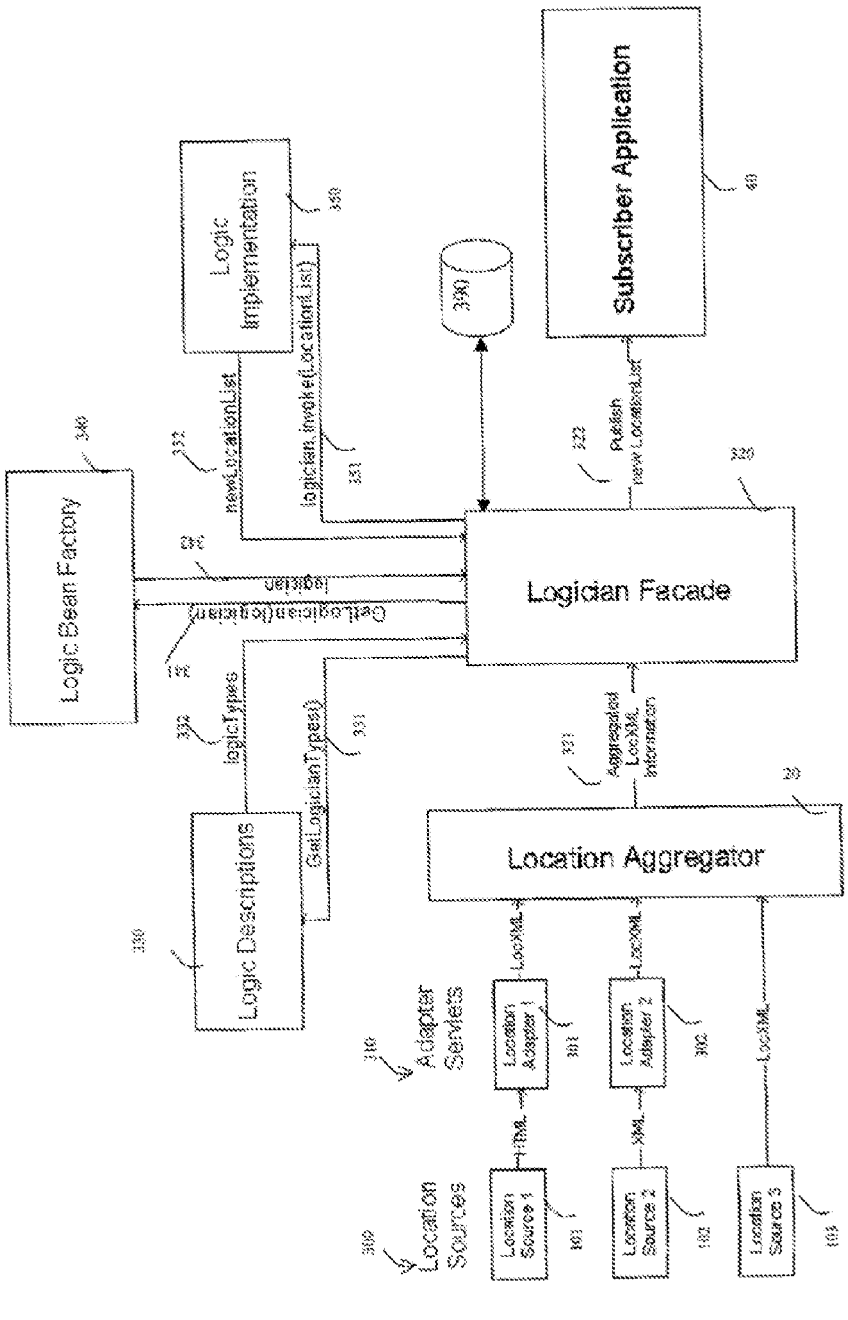

Logic Bean Factory
Logic Implementation
Subscriber Application
Logician Facade
Location Aggregator
Logic Descriptions
logicTypes
GetLogicianTypes()
logician
GetLogician(logician)
newLocationList
logician.invoke(LocationList)
Publish new LocationList
Aggregated LocXML Information
Adapter Servers
Location Sources
Location Adapter 1
Location Adapter 2
Location Source 1
Location Source 2
Location Source 3
LocXML
XML

Figure 3

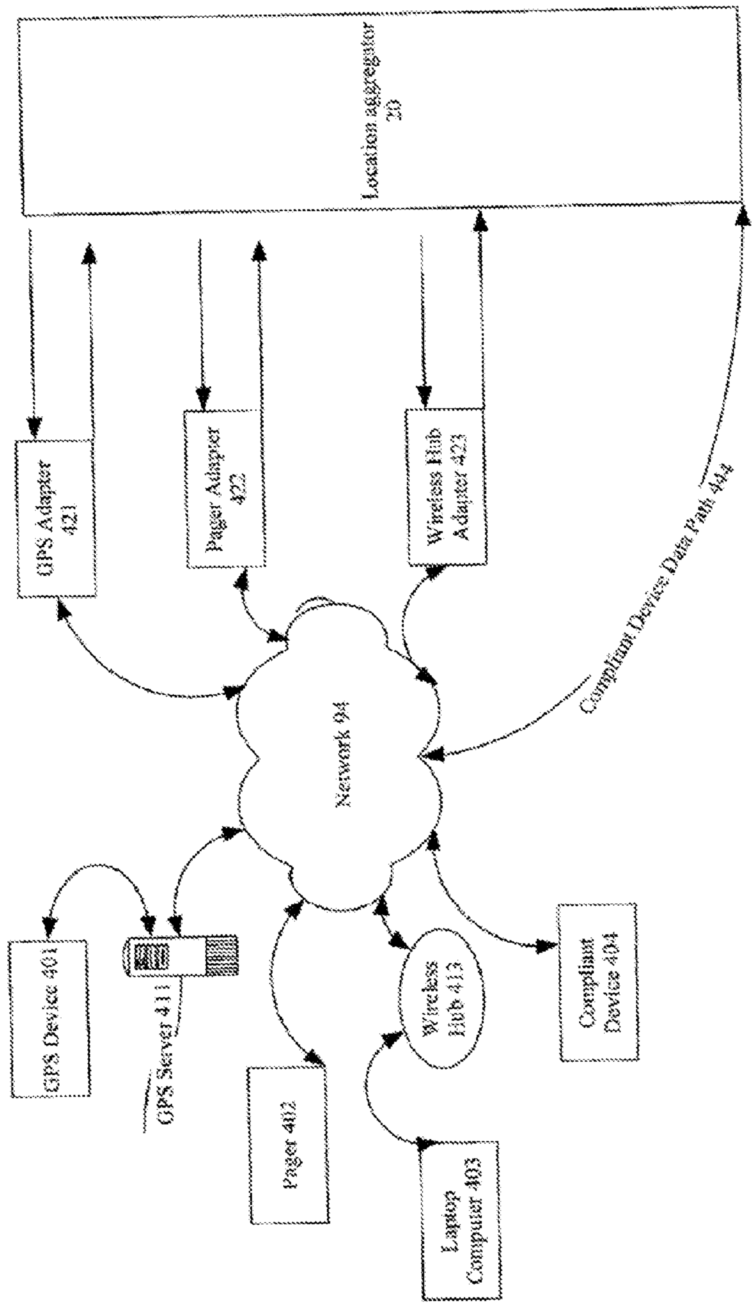

Location aggregator 20
GPS Adapter 421
Pager Adapter 422
Wireless Hub Adapter 423
Compliant Device Data Path 444
Network 94
GPS Device 401
GPS Server 411
Pager 402
Wireless Hub 413
Laptop Computer 403
Compliant Device 404

Figure 4

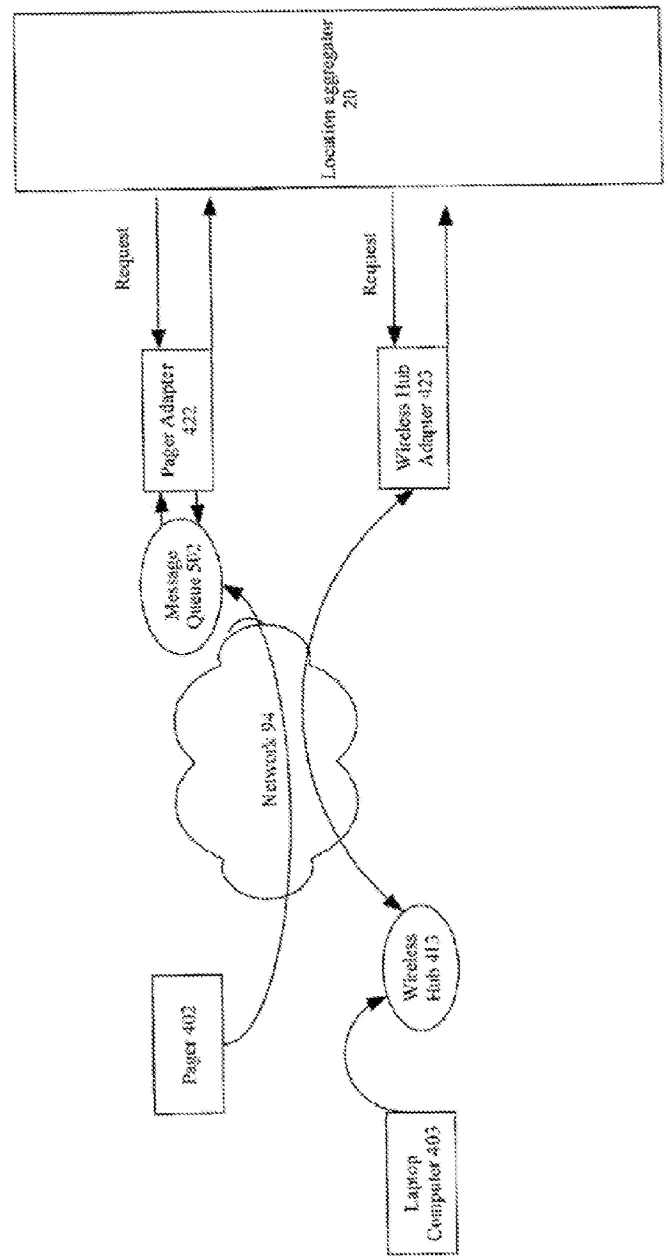

Location aggregator
20
Request
Request
Pager Adapter
422
Wireless Hub
Adapter 423
Message
Queue 502
Network 94
Pager 402
Wireless
Hub 413
Laptop
Computer 403

Figure 5

Figure 6

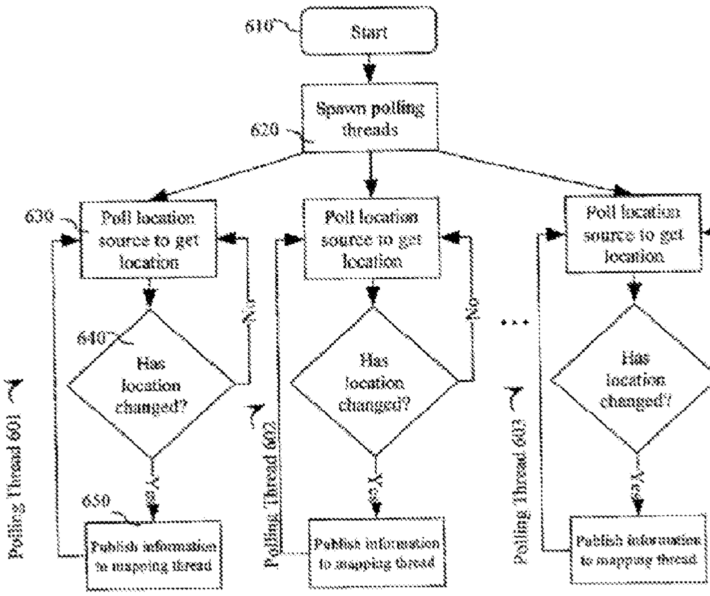

610
Start
620
Spawn polling threads
630
Poll location source to get location
640
Has location changed?
No
Yes
650
Publish information to mapping thread
Polling Thread 601
Poll location source to get location
Has location changed?
No
Yes
Publish information to mapping thread
Polling Thread 602
Poll location source to get location
Has location changed?
No
Yes
Publish information to mapping thread
Polling Thread 603

Figure 7

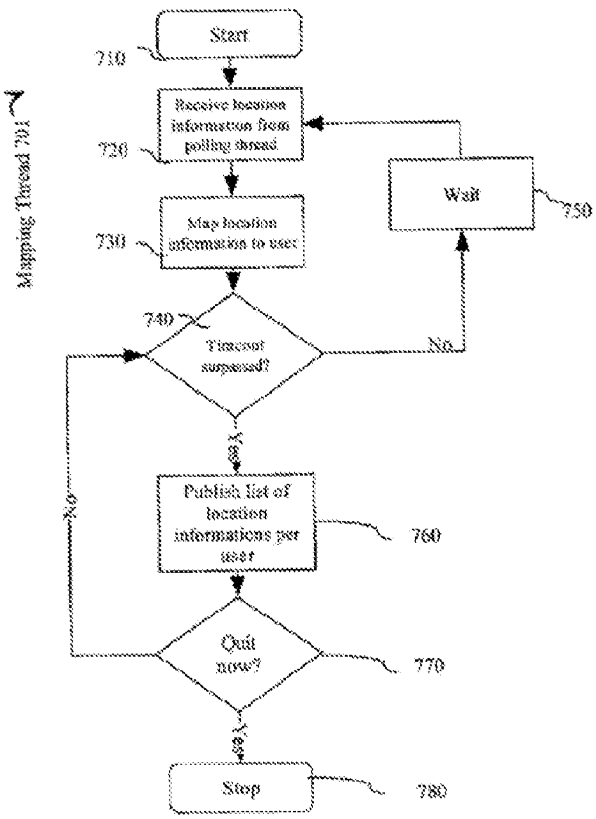

Mapping Thread 701
Start
710
Receive location information from polling thread
720
Map location information to user
730
Wait
750
740
Timeout surpassed?
No
Yes
Publish list of location informations per user
760
No
Quit now?
770
Yes
Stop
780

Figure 8

SAMPLE LOCATION XML DOCUMENT


```
- <LocationInformation>
 - <MobileDevice TrackID="1234567890" RequestTime="20000626115751+-0800" ErrorCode="0">
  - <Geographic Velocity="0" PositionTime="20000626115751+-0800">
   - <GeodeticDatum>
    - <WGS-84>
       <LatLong PositionFormat="IDM80" Latitude="N374820" Longitude="W1222738" />
      </WGS-84>
    </GeodeticDatum>
    <HeightDatum HeightFormat="meters" HeightValue="500" />
    <Region RadiusFormat="meters" InnerRadius="0" OuterRadius="100" StartAngle="0" StopAngle="360"
       LevelOfConfidence="100" />
   </Geographic>
   <TowerID PositionTime="20000626115751+-0800" Name="95110" Type="ZIP" />
  </MobileDevice>
 </LocationInformation>
```


811 832 833 871 872

SYSTEM AND METHOD FOR AGGREGATING INFORMATION TO DETERMINE A USER'S LOCATION

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application is related to a communication of an application entitled "System and Method for Aggregating Information to Determine Users' Location," Ser. No. 09/773,194, filed Jan. 31, 2001, assigned to the assignee of the present application, and herein incorporated by reference.

TECHNICAL FIELD

[0002] The present invention relates generally to information handling systems and more particularly to methods and systems that aggregate information to determine a user's location.

BACKGROUND OF THE INVENTION

[0003] Mobile, wireless electronic devices such as mobile telephones, personal digital assistants, and Global Positioning System (GPS) devices, have become very popular, and their use has become very common. It is common for one person to use two or more of these devices. These mobile device are a subset of a group of devices that are sometimes called "pervasive computing" devices. The term "pervasive computing" is used because systems with microprocessors are now found in any array of devices that previously were largely untouched by a computer technology. These pervasive computing devices include mobile devices such as cell phones and automobile components. Pervasive comprising devices often include a microprocessor and associated volatile and non-volatile memory, input means, output means, and interfaces, such as a network interface or modem, providing a link to other computing devices.

[0004] These pervasive computing devices are information handling systems, designated to give independent computing power to a single user, or a group of users in the case of networked pervasive computing devices. Pervasive computing devices may also include one or more input/output devices which are coupled to the microprocessor and which perform specialized functions (e.g. modems, sound and video devices, or specialized communication devices). Pervasive computing devices are often linked to computing systems and other pervasive computing devices using a network, such as a local area network (LAN), wide area network (WAN), or the Internet.

[0005] Satellite-based or network-based positioning technologies make it possible to determine the geographic location of mobile pervasive computing devices (e.g. location-based services for users of mobile telephones use such positioning technologies). One problem is that location information from one source may be inconsistent with information from another source. For example, a husband and wife may share a tracking device that is embedded in their car. in addition, the husband may have a location-aware mobile phone. The wife may use a car to drive to the wife's office, after giving the husband the ride to his office. Then information from the mobile phone, indicating that the husband is at his office, will be inconsistent with information from the tracking device in the car, indicating that the husband is at the wife's office.

[0006] Such an inconsistency could cause significant practical problems. To continue the example, the husband's employer may use location information from employees mobile electronic devices to determine the employees' location. The system would help the employer make good decisions about dispatching employees to make sales calls or service calls. However, this system could be defeated when information from one source indicates that the husband is at his office, and information from another source indicates that the husband is at the wife's office.

[0007] The inconsistency would be difficult to resolve, without additional information about the people involved, their schedules, and how they are associated with various mobile devices. To make the best use of these positioning technologies, it would be important to make use of all available information, from multiple sources, to determine users' locations. Thus there is a need for methods and systems that acquire, aggregate, and evaluate location information for multiple sources. There is a need for methods and systems that go beyond just locating a mobile device, to also include information about people, their schedules, and their various devices.

SUMMARY OF THE INVENTION

[0008] The present invention is a system and method that acquires and aggregates information, organized by user, to determine a user's location. If properly handled, such location information can be very useful. One example, dispatching employees to make sales calls or sevice calls, was mentioned above. The goal of the present invention is to allow users to collect and evaluate information from multiple sources, and this make proper use of all available location information.

[0009] Without such a method or system, positioning technologies cannot properly handle multiple location sources for a single user, or a single location source shared by multiple users. Without such a method or system, users would be left with the above-mentioned problem of location information from one source being inconsistent with information from another source.

[0010] The solution is to make proper use of all available location information, by first collecting and then evaluating information from multiple sources. Information from some sources generally would be more reliable than others. For example, information from a device that is not shared may be more reliable than information from a device that is shared by more than one user. Information from a device that recently changed position may be more reliable than information from a device that has not recently changed position.

[0011] Instead of merely locating a mobile device, the present invention locates people, i.e. users who may have more than one mobile device, and perhaps computerized calendars that indicate a person's expected location. The electronic sources of location data (hereinafter referred to as "location sources") for the present invention include mobile electronic devices such as mobile telephones, personal computing devices. Location sources also include computer-based models, schedules or calendars that give a person's expected location depending on the date and time. These models, schedules or calendars may be stored on personal digital assistants, desk-top computers, or servers, for example.

[0012] After location information is acquired from location sources, a user who is tracking the locations of other users might evaluate the collected location information himself or herself, or evaluation could be automated. In a fully automated system, a computer would perform ranking or filtering operations on the data before providing the information to the user.

[0013] One aspect of the present invention is a method for aggregation information to determine a user's location. Another aspect of the present invention is a system for executing the method of the present invention. A third aspect of the present invention is as a set of instructions on a computer-usable medium, or resident in a computer system, for executing the method of the present invention.

[0014] This summary is not intended as a comprehensive description of the claimed subject matter but, rather, is intended to provide a brief overview of some of the functionality associated therewith. Other systems, methods, functionality, features and advantages of the invention will be or will become apparent to one with skill in the art upon examination of the following figures and detailed description.

BRIEF DESCRIPTION OF THE FIGURES

[0015] A better understanding of the present invention can be obtained when the following detailed description is considered in conjunction with the following drawings. The use of the same reference symbols in different drawings indicates similar or identical items.

[0016] FIG. **1** is an exemplary block diagram of location data being delivered over a computer network with an information handling system, according to the teachings of the present invention;

[0017] FIG. **2** is a high-level block diagram illustrating selected components that may be included in the exemplary information handling system of FIG. **1**;

[0018] FIG. **3** is a high-level block diagram illustrating an example of a system for acquiring, aggregating, and evaluating location information, according to the teachings of the present invention;

[0019] FIG. **4** is a high-level based block diagram illustrating an example of a system for acquiring and aggregating location information, according to the teachings of the present invention;

[0020] FIG. **5** is a block diagram illustrating in greater detail selected components that may be included in the exemplary system of FIG. **4**.

[0021] FIG. **6** is a flow chart illustrating one type of process for acquiring and aggregating location information, as implemented in an exemplary embodiment;

[0022] FIG. **7** is a flow chart illustrating another process, related to the type shown in FIG. **6**, for acquiring and aggregating location information, as implemented in an exemplary embodiment.

[0023] FIG. **8** is a sample Location XML document, according to the teachings of the present invention, showing location data from a two-way pager with GPS capability, as viewed with a browser.

DETAILED DESCRIPTION OF THE FIGURES

Overview

[0024] The present invention is a system and method that acquires and aggregates location information. A user might evaluate the collected location information himself or herself, or evaluation could be automated. The present invention could be useful in any situation involving location information from multiple sources. One example, a system using collected location information for dispatching employees to make sales calls or service calls, is mentioned above. Another example would be a system to alert a first user that a second user of particular interest has arrived at a meeting site. Another example would be a system interacting via the World Wide Web with a user's hand-held computer, his computer-based calendar, his GPS unit, and a map service, to provide appropriate driving directions to his next meeting site. Another example would be a system interacting via the World Wide Web with a user's cell phone, and her computer-based calendar or to-do list, alerting a mobile user when she approaches a site where some business needs to be transacted. In these examples, information output could be audible or visible, by text or graphics.

[0025] In these examples, note that a user would be provided with useful information keyed to a user's actual location, and the user would not need to make a query. Also note the importance of using all available location information, from multiple sources, organized by user.

[0026] The following are definitions of terms used in the description of the present invention and in the claims. "Computer-usable medium" means any signal or transmission facility for communication with computers, and any kind of computer memory, such as floppy disks, hard disks, Random Access Memory (RAM), Read Only Memory (ROM), CD-ROM, flash ROM, non-volatile ROM, and non-volatile memory. "Location data" or "location information" means latitude and longitude, or any other descriptions of location "Location sources" or "Location sources" means any electronic source of location data. including mobile electronic devices such as mobile telephones, personal digital assistants, pagers, Global Positioning System (GPS) devices, servers associated with these mobile electronic devices, and computer-based models, schedules or calendars that give a person's expected location depending on the date and time. "Users" or "user" means any person utilizing location sources being tracked by the method or system of the present invention and any person tracking the locations other users.

System and Method

[0027] The present invention is not limited as to the type of computer on which it runs. Referring now to FIG. **1**, an exemplary block diagram shows location data being delivered over a computer network with an information handling system, according to the teachings of the present invention. At the left side of FIG. **1**, location information is acquired from location sources device **101**, server **111**, device **102**, device **103**, and device **104**. Location data is delivered over a computer network **94** to information handling system **10**. Within information handling system **10**, location aggregator **20** acquires location data regarding a user, or more than one user, and creates collections of said location data regarding a user, or more than one user, organized by user. In this example, evaluation of the collected location information is automated. A logic component, location logician **30**, performs evaluation (ranking, filtering, or consolidating operations) on the data before providing the information to a user through a subscriber application **40**.

[0028] Referring now to FIG. **2**, a high-level diagrams illustrates selected components that may be included in the exemplary information handling system **10** of FIG. **1**. Information handling system **10** is controlled primarily by computer readable instructions, which may be in the form of software, wherever, or by whatever means such software is stored or accessed. Such software may be executed within the processor, also known as the Central Processing Unit (CPU) **50** to cause information handling system **10** to do work CPU **50** typically is a microprocessor of the kind available from Intel Corporation or Advanced Micro Devices, Inc.

[0029] Memory devices coupled to system bus **5** include Random Access Memory (RAM) **56**, Read Only Memory (ROM) **58**, and non-volatile memory **60**. Such memories include circuitry that allows information to be stored and retrieved. ROMs contain stored data that cannot be modified. Data stored in RAM can be changed by CPU **50** or other hardware devices. Non-volatile memory is memory that does not lose data when power is removed from it. Non-volatile memories include ROM, EPROM, flash memory, or battery-pack CMOS RAM. As shown in FIG. **2** such battery-pack CMOS RAM may be used to store configuration information. An expansion card or board is a circuit board that adds functions or resources to the computer. Typically expansion cards add memory, disk-drive controllers **66**, video support, parallel and serial ports, and internal modems. For laptop, palm top, and other portable computers, expansion cards usually take the form of PC cards, which are credit card-sized devices designed to plug into a slot in the side or back of a computer. Thus, empty slots **68** may be used to receive various types of expansion cards or PC cards. Disk controller **66** and diskette controller **70** both include special purpose integrated circuits and associated circuitry that direct and control reading from and writing to hard disk drive **72**, and a floppy disk or diskette **74**, respectively. Such disk controllers handle tasks such as positioning a read/write head. A single disk controller may be able to control more than one disk drive. CD-ROM controller **76** may be included in information handling system **10** for reading data from CD-ROM **78** (compact disk read only memory). Such CD-ROMs use laser optics rather than magnetic means for reading data.

[0030] Communication between information handling system **10** and other information handling systems may be facilitated by serial controller **88** and network adapter **90**, both of which are coupled to system bus **5**. Serial controller **88** is used to transmit information between computers, or between a computer and a peripheral devices, one bit at a time over a single line. As illustrated, such a serial interface may be used to communicate with modem **92**. A modem is a communicator device that enables a computer to transmit information over a standard telephone line. Modems convert digital computer signals to analog signals suitable for communications over telephone lines. Modem **92** or network adapter **90** may provide a connection to sources of software and information, such as a server, an electronic bulletin board, the Internet or World Wide Web. Network adapter **90** is a communication device that may be used to connect information handling system **10** to a network **94**. Network **94** may provide computer users with means of communicating and transferring software and information electronically. Additionally, network **94** may provide distributed processing, which involves several computers in the sharing of workloads or cooperative efforts in performing task.

[0031] Keyboard mouse controller **80** is provided in information handling system **10** for interfacing with keyboard **82** and pointing device **84**, which may be implemented using a track ball, a joy stick, touch sensitive tablet or screen, or as illustrated, a mouse. The pointing device **84** may be used to move a pointer or cursor visible on display **96**. Another example of an input device would be a pointer or cursor visible on display **96**. Another example of an input device would be a microphone for audio input. It should be noted and recognized by those persons of ordinary skill in the art that display **96**, keyboard **82**, and pointing device **84** may each be implemented using any one of several known off-the-shelf components.

[0032] Display **96**, which is controlled by display controller **98**, is used to display visual output generated by information handling system **10**. Display **96** includes a display screen which may be implemented using a cathode ray tube (CRT) a liquid crystal display (LCD) an electrode luminescent panel or the like. Display controller **98** includes electronic components required to generate a video signal that is sent to display **96**. Printer **100** may be copied to information handling system **10** via parallel controller **102**. Parallel controller **102** is used to send multiple data and control bits simultaneously over wires connected between system **5** and another parallel communication device, such as printer **100**. Another example of an output device would be a speaker for audio output.

[0033] CPU **50** fetches, decodes, and executes instructions, and transfers information to and from other resources via the computer's main data-transfer path, system bus **5**. Such a bus connects the components in an information handling system **10** and defines the medium for data exchange. System **5** connects together and allows for the exchange of data between memory units **56**, **58** and **60**. CPU **50**, and other devices as shown in FIG. **2**

[0034] Referring now to FIG. **3**, a diagram is shown illustrating an example of a system for acquiring, aggregating, and evaluating location information, according to the teachings of the present invention. In the invention as currently implemented, the Java programming language was used, but other languages could be used. At the left side of FIG. **3**, location information is acquired from a group of location sources **300**, including location source **101**, location source **102**, and location source **103**, in this example.

[0035] Output from location sources **300** could be in hypertext markup language (HTML), extensible markup language (XML), or some other language. In the invention as currently implemented, location information is acquired through a set of adapter servlets **310**, including adapter **301** and adapter **302**, in this example. These adapters convert location data from various location sources to a single format. In the invention as currently implemented, the single format was implemented in XML, named "Location XML" or "LocXML." Location data also could be acquired directly, as form location source **103** in this example, Further description of adapters is given below, in connection with FIG. **4**.

[**0036**] Location aggregator **20** acquires location data regarding a user, or more than one user, and creates collections of said location data regarding a user, or more than one user, organized by user. Collections of location data, shown as aggregated LocXML information **321**, are sent to logician facade **320**, which communicates with logic descriptions **330**, logic bean factory **340**, and logic implementation **350**. These are described in more details below. These function to perform evaluation (ranking, filtering, or consolidating operations) on the data before providing the information to a user, by publishing new location list **322** to subscriber application **40**. In another embodiment, some ranking or filtering could be performed by the location aggregator **20**.

[**0037**] Regarding ranking, filtering, or consolidating operations, different kinds of logic functions could be chosen by a user and implemented as follows. Any logic function or process that is used for ranking, filtering, or consolidating location data is called a "logician" To "invoke" or "implement" a logician is to employ the logician for ranking, filtering, or consolidating certain location data. As a result of the API call GetLogicianTypes ( ) **331**, logic descriptions **330** returns logician types **332**. This represents choices being presented to a user. As a result of the API call GetLogician (logician) **341**, logic bean factory **340** returns logician **342**. This represents a user choosing a kind of logic function to implement. User preferences regarding logic functions could be stored in and retrieved from subscriber preferences database **390**. As a result of API call logician invoke (LocationList) **351**, logic implementation **350** returns newLocationList **352**. This represents a chosen kind of logic function being implemented to rank, filter, or consolidate location data. (Logic implementation **350** corresponds with location logician **30** shown in the simplified diagram in FIG. **1**.) By publishing new location list **322** to subscriber application **40**, the system provides a user with location data that is ranked, filtered, or consolidated.

[**0038**] The system may rank items in a collection of location information, according to expected utility. A user who is tracking the locations of another user may be provided with location data such that a higher ranking is given to data from location sources that indicate more recent movement. This is an example of ranking data according to which location source moved more recently, and thus generated the most recent location update. In the invention as currently implemented, each Location XML entry has a time stamp, and collections of location data are sorted by time stamp. In another example of ranking, a user who is tracking the locations of another user may be provided with location data such that a higher ranking is given to data from location sources that are expected to be more accurate than the other location sources. Another option would give a higher ranking to data from location sources that are capable of more precise measurement.

[**0039**] To give an example of filtering data sudden small changes in reported location could be caused by random variation in location measurement, not actual movement. This is a type of noise that can be filtered out, by setting limits on which pieces of new location data are added to a collection of current location data. Thus the system may filter data to remove misleading data.

[**0040**] The present invention would be capable of consolidating location data found in a collection of location data, to determine the most likely location of a user. For example, a user may be provided with the most likely location of another user who is being tracked, as a result of the system determining a consensus location, based on data from more than one location source. A consensus location, indicated by data from any one location source taken alone.

[**0041**] Through feedback from users regarding actual location, and conventional artificial intelligence algorithms, the system could learn to improve its performance. The system could learn which location source, or combination of location sources, are most useful.

[**0042**] To continue with an example given above, an employer may use location information from employees mobile electronic devices to determine the employees location. This system would help the employer make good decisions about dispatching employees to make sales calls or service calls. The present invention would make such a system more useful. An employer could use the present invention as follows. Referring again to FIG. **3**, logic descriptions **330** returns logician types **332**. This represents choices being presented to a user, such as an employer. The choices may be presented in a menu, including "most-recently-moved,""most precise," and other options. Logic data factory **340** returns logician **342**. This represents a user choosing a kind of logic function to implement. An employer may choose "most-recently-moved." For this logician the rule could be stated this way: "rank data according to which location source moved more recently, and thus generated the most recent location update." This is an example of ranking items in a collection of location information, according to expected utility.

[**0043**] To continue with an example given above, a husband and wife may share a tracking device that is embedded in the car. In addition, the husband may have a two-way pager with GPS capability. At mid-day, perhaps the shared car has not moved for a few hours, but the husband with his two-way pager has been moving frequently. The husband may have moved around the employer's plant, and then traveled in an employer-owned vehicle to call on a customer. The employer may track the husband. Logic implementation **350** returns newLocationList **352**. This represents a "most-recently-moved" logic function being implemented to rank location data. By publishing new location list **322** to subscriber application **40**, the system provides the employer with location data that is ranked. Location data from the husband's two-way pager would be at the top of the list, ranked above location data from the shared car that has not moved for a few hours. The list may appear as a list of entries like the example in FIG. **8** below. Subscriber application **40** could help the employer to interpret the location data by displaying a map, for example. Subscriber application **40** could display a simplified version of the location data, to suit a user's preferences. The following table is a simplified example of a collection of location data regarding a user, such as the husband in the preceding example.

Location data for husband

Rank	Location Source	Location
1.	Pager	Latitude = N374820 Longitude = W1222738
2.	Car	Latitude = N374822 Longitude = W1222740

Such a collection could include entries from additional location sources such as a calendar or cell phone.

[0044] FIG. **4** is a high-level block diagram illustrating an example of a system for acquiring and aggregating location information according to the teachings of the present invention. In this example, location aggregator **20** polls location sources GPS server **411**, a maintain a carrier synchronized to its secondary fundamental voltage at a desired angle relative to such a voltage, and a method of determining the difference between the primary voltage and each cell's secondary voltage. Any methods of calculation now or hereafter known may be used.

[0045] In the methods described herein, although a master clock may be used to determine an initial offset value, the master clock need not be used when performing synchronization, as the system has determined a set phase relationship for each carrier signal to the fundamental. Thus, a synchronizing clock signal is not required after the initial offset is determined.


```
<!--DTD for location information from mobile devices-->
<!ELEMENT LocationInformation (MobileDevice+)>
<!ELEMENT MobileDevice (Geographic+,TowerID?)>
<!ATTLIST MobileDevice TrackID CDATA #REQUIRED>
<!ATTLIST MobileDevice RequestTime CDATA #REQUIRED>
<!ATTLIST MobileDevice ErrorCode CDATA #REQUIRED>
<!ELEMENT Geographic (GeodeticDatum, HeightDatum, Region)>
<!ATTLIST Geographic Velocity CDATA #IMPLIED>
<!ATTLIST Geographic PositionTime CDATA #REQUIRED>
<!ELEMENT GeodeticDatum (WGS-84 | BESSEL-1841)>
<!ELEMENT WGS-84 (LatLong | UTM)>
<!ELEMENT LatLong EMPTY>
<!ATTLIST LatLong PositionFormat (IDMS0 | IDMS3) #REQUIRED>
<!ATTLIST LatLong Latitude CDATA #REQUIRED>
<!ATTLIST LatLong Longitude CDATA #REQUIRED>
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<!ATTLIST UTM Positionformat (2 | 4) #REQUIRED>
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[0046] The controller may then pass **418** the carrier offset angle to the appropriate cell with a phase angle offset with respect to the fundamental line voltage that results in the carrier signal being interdigitated with other carrier signals delivered to other cells. The carrier offset angle may be delivered to the cell as a synchronization signal that represents the phase angle relationship between the input voltage (i.e., the source or transformer primary voltage) and the actual secondary voltage in each cell. The synchronization signal may be part of the PWM carrier, or it may be delivered as a separate signal. The cell then synchronizes **420** its carrier signal to the secondary signal using the offset angle that it receives from the controller.

[0047] FIG. **5** illustrates how multiple carrier signals **510**, **520**, **530**, etc. for multiple cells may be interdigitated with each other in a synchronized manner to a reference signal **550**, as reflected to the primary windings of the source transformer Each cell may have its own reference signal, and the reference signals for each cell will be similar but not necessarily the same. The carrier signal in each cell will determine when a switching command occurs within that cell. As shown in FIG. **5**, since each carrier signal is phase-shifted from the carrier signals from the other cells by a predetermined amount (2_0), the effect of the switching commands for each cell as reflected to the primary of the transformer will be spaced out over a period of time based on the $\mathbf{2}_0$ value, or the spacing of the interdigitation. Thus, instead of all cells effectively implementing the same switching operation at the same time (which would cause a large harmonic disturbance), the effect of the switching operations at the primary of the transformer occur in rapid sequence based on the substantially even offset of the carrier signals. In addition, since the effective frequency of the carrier signals seen at the source transformer primary is relatively high (such as on the order of about $f_c \cdot N$), the harmonics may be further smoothed, as the impedance of the source transformer itself may filter our some or all of the high-frequency harmonics.

[0048] In some embodiments, multiple drives may be connected to a single transformer or a group of transformers sharing a common primary voltage. In such a situation, multiple drives may have their carrier signals interdigitated by adjusting the drive carrier offset angle (2_R) for each drive and setting each drive to the same carrier frequency.

[0049] In the embodiments provided herein, the interdigitation of the carrier signals may increase the frequency of the voltage harmonics and reduce the peaks of the voltage harmonics, which in turn may reduce current harmonics. For example, FIG. **6** illustrates an exemplary trace of one phase of voltage **610** and current **620** delivered to a load from a drive having twenty-one regenerative power cells using a source transformer rated for 7200 volts primary and 600 volts secondary. In the data shown in FIG. **6**, although the source transformer had phase-shifted secondaries, carrier de-synchronization (i.e., the shifting of the carrier signals by an offset) was not performed, and both voltage and current harmonics are obvious in the traces. FIGS. **7** and **8** show traces of current **720** and voltage **810** on the same circuit after the application of carrier synchronization methods such as those described herein.

[**0050**] In some embodiments, interdigitation of the switching events may occur using known methods other than adjustment of a carrier signal. For example, if space vector modulation is used instead of sine triangle methods as described herein, the method still may include interdigitating the effective timing of switching events as reflected to the primary.

[**0051**] Still other embodiments will become readily apparent to those skilled in this art from reading the above-recited detailed description and drawings of certain exemplary embodiments. It should be understood that numerous variations, modifications, and additional embodiments are possible, and accordingly, all such variations, modifications, and embodiments are to be regarded as being within the spirit and scope of this application

What is claimed is:

1. A method of controlling a power delivery system, comprising:

operating a system comprising a plurality of power cells that are electrically connected to a first transformer comprising one or more primary windings and a plurality of secondary windings such that each cell is electrically connected to one of the secondary windings and a plurality of the secondary windings are phase-shifted with respect to the primary windings, wherein each cell includes a plurality of switching devices; and

controlling the timing of activation of the switching devices within each cell so that an effective frequency of the activation for all of the cells as reflected to the primary is at least three times greater than the switching frequency of any individual cell.

2. The method of claim 1, wherein the controlling does not require the use of a synchronizing clock signal.

3. The method of claim 1, wherein the controlling comprises:

determining a carrier offset angle;

passing the carrier offset angle to the first power cell; and

synchronizing, by the first power cell, a carrier signal to the first secondary voltage based on the carrier offset angle.

4. The method of claim 3, further comprising, synchronizing, by each additional cell in the system, an additional carrier signal to a secondary voltage for each additional cell.

5. The method of claim 3, wherein the carrier signals for each cell are interdigitated so that they are distributed substantially evenly when reflected toward the primary windings of the source transformer.

6. The method of claim 3, wherein the carrier signal also controls the timing of implementation of commands that control the switching devices.

7. The method of claim 6, wherein the switching devices are part of an AC-to-DC converter portion of the cell.

8. The method of claim 6, wherein when a plurality of the cells determine that switching commands must be implemented, the carrier offset angle for each cell ensures that the commands are effectively interdigitated as reflected to the primary of the transformer.

9. The method of claim 8, wherein:

a command is implemented by the first power cell at a frequency substantially equal to a multiple of a fundamental frequency.

10. The method of claim 3, wherein the carrier offset angle represents a phase relationship between the carrier signal of the first cell and the first secondary voltage.

11. The method of claim 3, further comprising:

operating a second system comprising a second transformer and a second plurality of power cells, wherein:

the second transformer comprises one or more primary windings and a plurality of secondary windings;

the primary windings of the second transformer are electrically connected to the primary windings of the source transformer at a common point; and

each power cell in the second system generates a carrier signal;

wherein the carrier signals for each cell in the second system are interdigitated so that they are distributed substantially evenly when reflected toward the primary windings of the secondary transformer.

12. A method of operating a power delivery system, comprising:

operating a system comprising a plurality of power cells that are electrically connected to a first transformer comprising one or more primary windings and a plurality of secondary windings such that each cell is electrically connected to one of the secondary windings and a plurality of the secondary windings are phase-shifted with respect to the primary windings, wherein each cell includes a plurality of switching devices;

wherein a first secondary winding is electrically connected to deliver power to a first power cell;

determining a carrier offset angle;

passing the first carrier offset angle to the first power cell;

synchronizing, by the first power cell, a carrier signal to the first secondary voltage based on the first carrier offset angle; and

for a second cell that is connected to a second secondary winding of the source transformer, wherein the second secondary winding has a voltage that is phase-shifted with respect the voltage of the first secondary winding, synchronizing a second carrier signal to the second secondary voltage using a second carrier offset angle.

13. The method of claim 12, wherein the carrier signals for each cell that is electrically connected to the source transformer are interdigitated so that they are distributed substantially evenly when reflected toward the primary windings of the source transformer.

14. The method of claim 12, wherein:

the carrier signal for each cell also controls the timing of implementation of commands that control the switching devices; and

the synchronizing controls the timing of activation of the switching devices within each cell so that an effective frequency of the activation for all of the cells as reflected to the primary is at least three times greater than the switching frequency of any individual cell.

15. The method of claim 14, wherein the commands control switching devices that are part of an AC-to-DC converter portion of each cell.

16. The method of claim 14, wherein when a plurality of the cells determine that switching commands must be implemented, the commands are effectively interdigitated as reflected to the primary of the transformer.

17. The method of claim 14, wherein:

a command is implemented by the first power cell at a frequency substantially equal to a multiple of a fundamental frequency.

18. The method of claim 12, wherein the carrier offset angle represents a phase relationship between the carrier signal of the first cell and the first secondary voltage.

19. A method of operating a power delivery system, comprising:

operating a system comprising a plurality of power cells that are electrically connected to a multi-winding machine comprising one or more primary windings and a plurality of secondary windings such that each cell is electrically connected to one of the secondary windings and a plurality of the secondary windings are phase-shifted with respect to the primary windings;

determining, for each cell in a set of the power cells, a carrier offset angle;

synchronizing, by the each cell in the set, a carrier signal to the secondary voltage for the cell based on the carrier offset angle determined for the cell; and

wherein the carrier signal for each cell controls the timing of operation of switching devices within the cell.

20. The method of claim 19 wherein a switching frequency for all of the cells is at least three times greater than a switching frequency for any individual cell's carrier signal.

21. A power delivery system, comprising:

a plurality of power cells that are electrically connected to a first transformer comprising one or more primary windings and a plurality of secondary windings such that each cell is electrically connected to one of the secondary windings and a plurality of the secondary windings are phase-shifted with respect to the primary windings; and

a plurality of switching devices included within each cell is timed, wherein timing of activation of the switching devices within each cell so that an effective frequency of the activation for all of the cells as reflected to the primary is at least three times greater than the switching frequency of any individual cell.

22. The system of claim 21, wherein a synchronizing clock signal is not required for activation of the switching devices.

23. The system of claim 21, wherein the effective frequency is determined by a carrier offset angle, passing the carrier offset angle to the first power cell, and synchronizing, by the first power cell, a carrier signal to the first secondary voltage based on the carrier offset angle.

24. The system of claim 21, wherein each cell includes a carrier signal interdigitated so that they are distributed substantially evenly when reflected toward the primary windings of the source transformer.

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