US007525207B2

(12) **United States Patent**
    Clidaras et al.

(10) **Patent No.:** **US 7,525,207 B2**
(45) **Date of Patent:** **Apr. 28, 2009**

(54) **WATER-BASED DATA CENTER**

(75) Inventors: **Jimmy Clidaras**, Los Altos, CA (US);
    David W. Stiver, Santa Clara, CA (US);
    William Hamburgen, Palo Alto, CA
    (US)

(73) Assignee: **Google Inc.**, Mountain View, CA (US)

(*) Notice: Subject to any disclaimer, the term of this
    patent is extended or adjusted under 35
    U.S.C. 154(b) by 237 days.

(21) Appl. No.: **11/679,013**

(22) Filed: **Feb. 26, 2007**

(65) **Prior Publication Data**

    US 2008/0209234 A1   Aug. 28, 2008

(51) **Int. Cl.**
    F03B 13/10   (2006.01)
    H02P 9/04   (2006.01)
(52) **U.S. Cl.** **290/43**; 290/42; 290/53;
                                                    290/54
(58) **Field of Classification Search** 290/42,
                    290/43, 44, 53, 54, 55; 415/2
    See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,781,023	A	*	11/1988	Gordon	60/506
6,020,653	A	*	2/2000	Woodbridge et al.	290/53
6,100,600	A	*	8/2000	Pflanz	290/54
6,559,552	B1	*	5/2003	Ha	290/54
6,813,897	B1		11/2004	Bash et al.	
6,833,631	B2	*	12/2004	Van Breems	290/42
6,953,328	B2		10/2005	Welch, Jr. et al.	
7,059,123	B2		6/2006	Welch, Jr. et al.	
7,105,939	B2	*	9/2006	Bednyak	290/42
7,257,946	B2		8/2007	Welch, Jr.	
7,258,532	B2		8/2007	Welch, Jr. et al.	
7,269,751	B2		9/2007	Janakiraman et al.	
7,278,273	B1		10/2007	Whitted et al.	
7,298,056	B2	*	11/2007	Gizara	290/54
7,331,174	B2		2/2008	Welch, Jr. et al.	
7,453,165	B2	*	11/2008	Hench	290/53
2007/0281639	A1		12/2007	Clidaras et al.	
2008/0029250	A1		2/2008	Carlson et al.	
2008/0055846	A1		3/2008	Clidaras et al.	
2008/0055848	A1		3/2008	Hamburgen et al.	
2008/0055850	A1		3/2008	Carlson et al.	

OTHER PUBLICATIONS

Cringley, Robert, "Google-Mart: Sam Walton Taught Google More
About How to Dominate the Internet Than Microsoft Ever Did," I,
Cringely—The Pulpit, Nov. 17, 2005, 3 pages.
Pelamis Wave Power, "P-750 Wave Energy Converter," Sep. 2007, 8
pages.
Rackable Systems, "Rackable Systems Contcentro Modular Data
Center high Density, High Efficiency Mobile Computing,"
Datasheet, 2007, 1 page.
Renewable Energy World, "Pelamis Waqve Energy Converter is
Launched," available at http://www.renewableenergyworld.com/rea/
news/story?id=10639, Retrieved Mar. 3, 2004, 4 pages.

(Continued)

Primary Examiner—Nicholas Ponomarenko
(74) *Attorney, Agent, or Firm*—Fish & Richardson P.C.

(57) **ABSTRACT**

A system includes a floating platform-mounted computer
data center comprising a plurality of computing units, a sea-
based electrical generator in electrical connection with the
plurality of computing units, and one or more sea-water cool-
ing units for providing cooling to the plurality of computing
units.

18 Claims, 7 Drawing Sheets
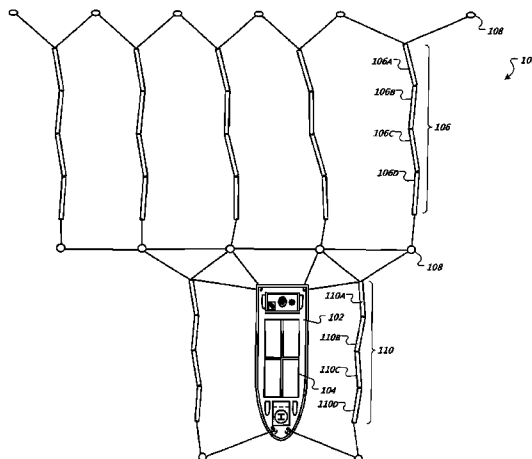
OTHER PUBLICATIONS

Shankland, Stephen, "Sun Blackbox, meet APC's whitebox," cNet News.com, available at http://news.com.com/Sun+Blackbox%2C+meet+APCs+whitebox/2001-1010_3-617774.html, Jan. 7, 2007, 2 pages.

SRP, "Wave Energy Project Based on Prelamis Technology in New Caledonia," Oct. 24, 2007, 8 pages.

Sun Project Blackbox-Index, Available at: http://www.sun.com/emrkt/blackbox/index.jsp, Retrieved Oct. 19, 2006, 3 pages.

Sun Project Blackbox-Scenarios, Available at: http://www.sun.com/emrk/blackbox/senarios.jsp, Retrieved Oct. 19, 2006, 7 pages.

Wikipedia, "Pelamis Wave Energy Converter," available at http://en.wikipedia.org/wiki/Pelamis_Wave_Energy_Converter, Retrieved Dec. 12, 2008, 3 pages.
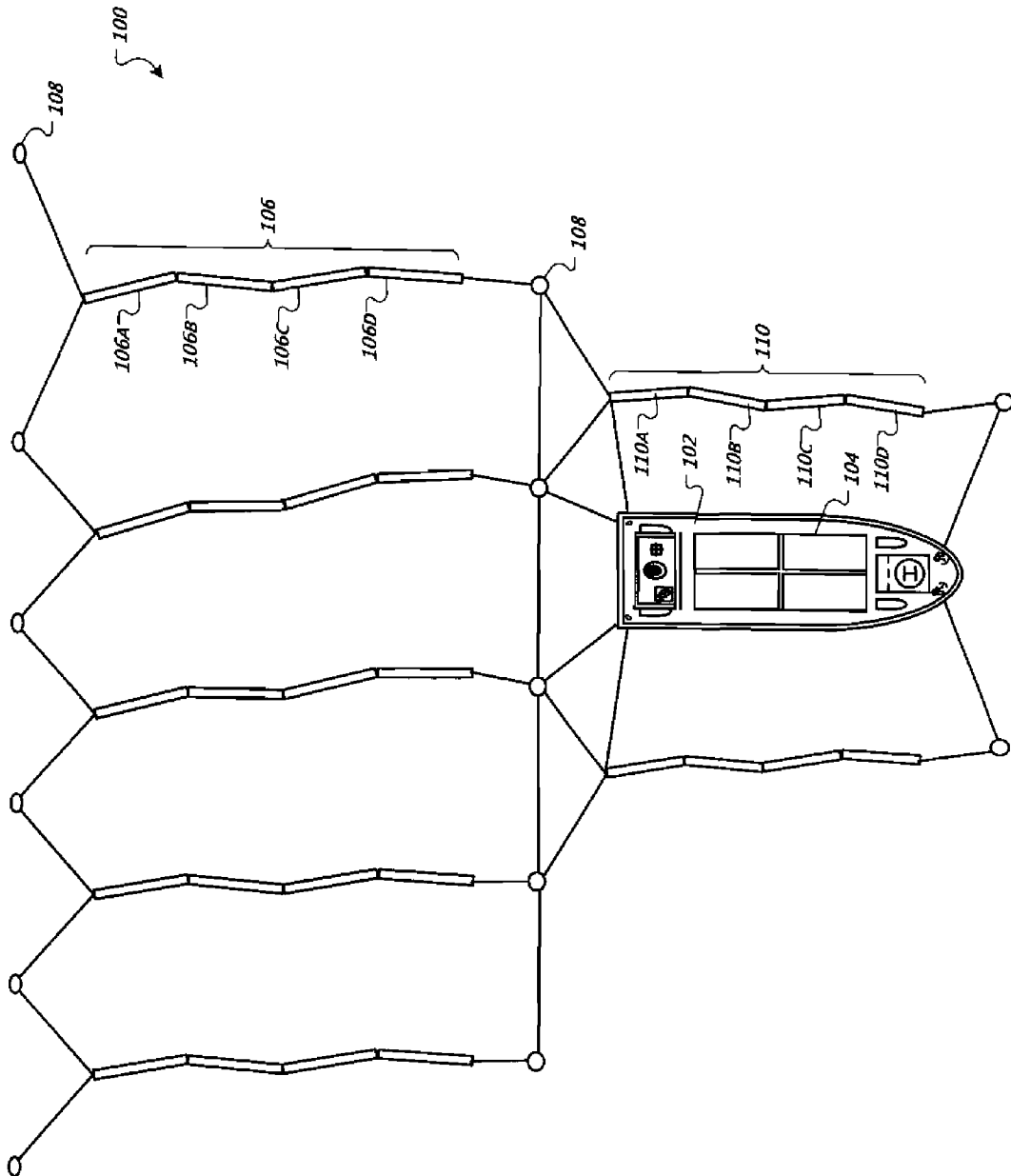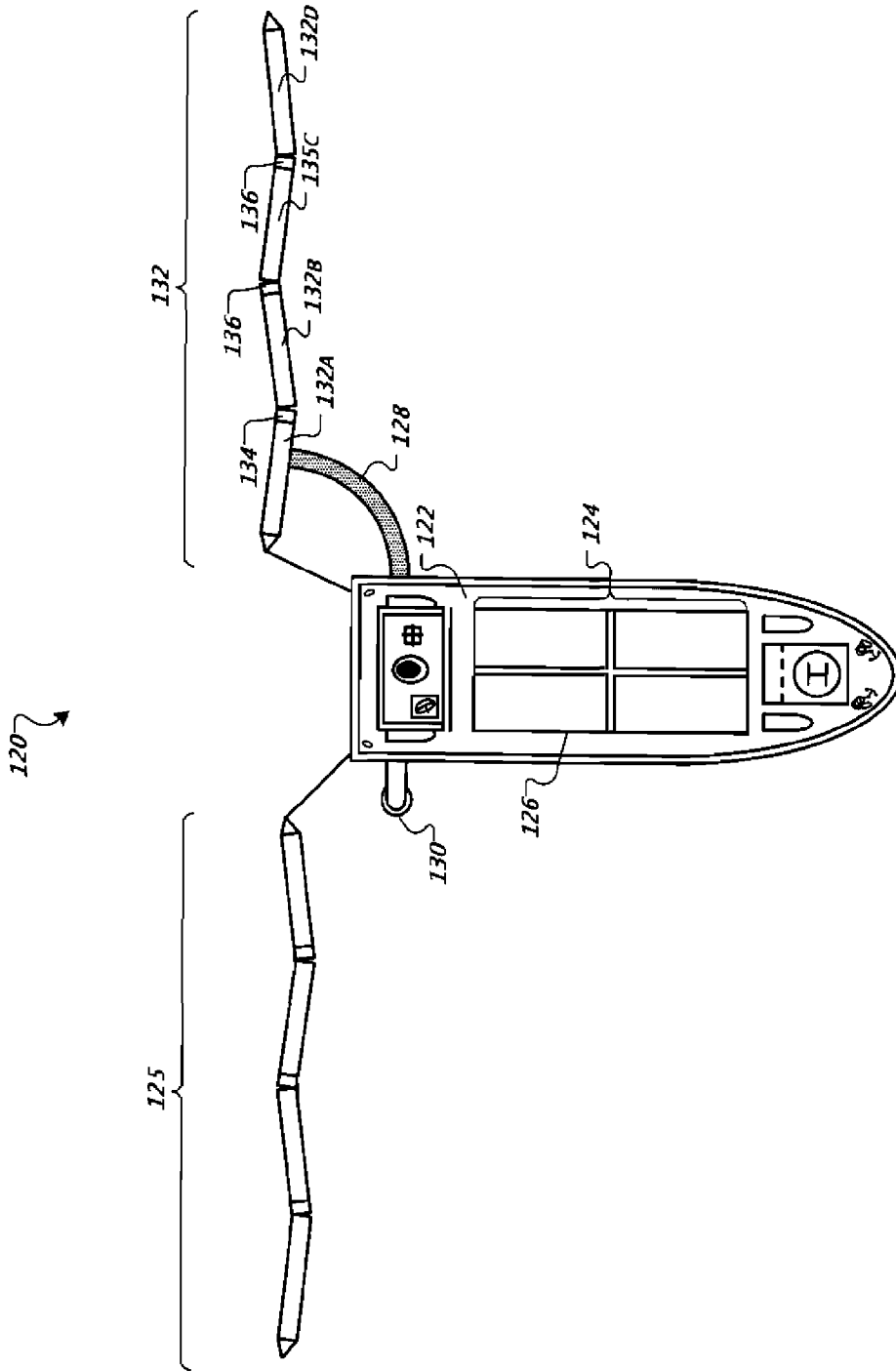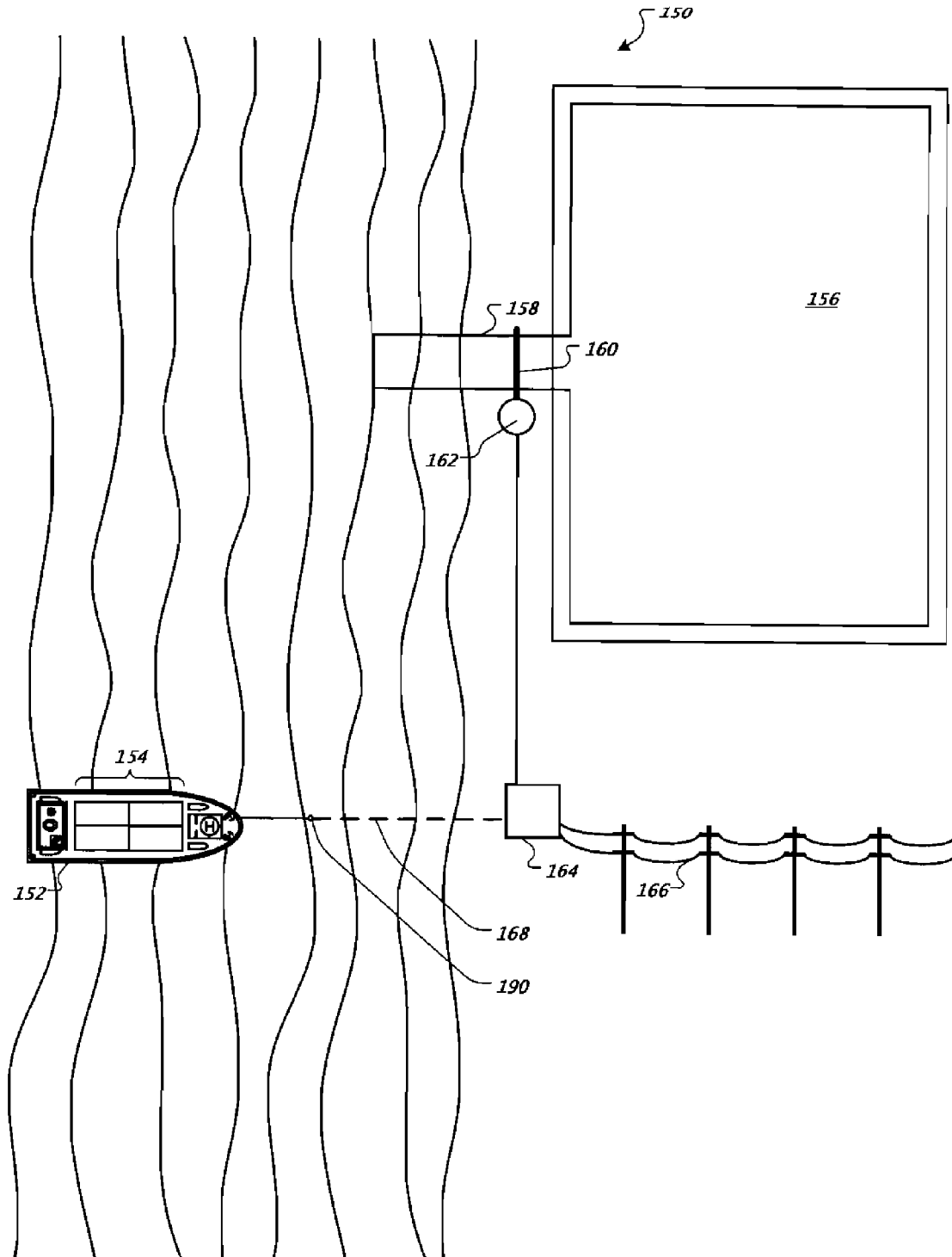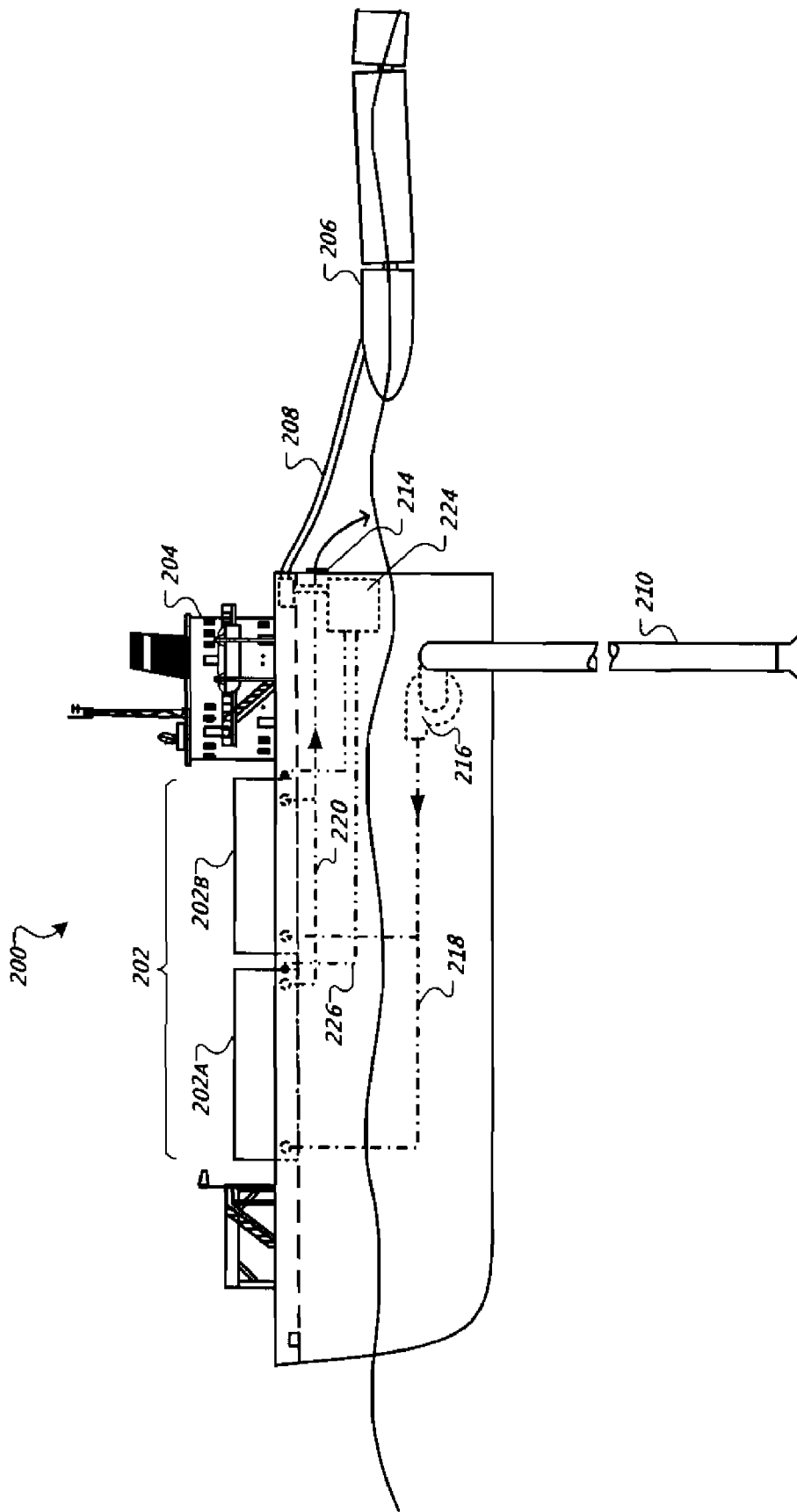
* cited by examiner

FIG. 1A

FIG. 1B

FIG. 1C

FIG. 2

FIG. 3

FIG. 4

500

514

508

516

506

504

507

512

520

502
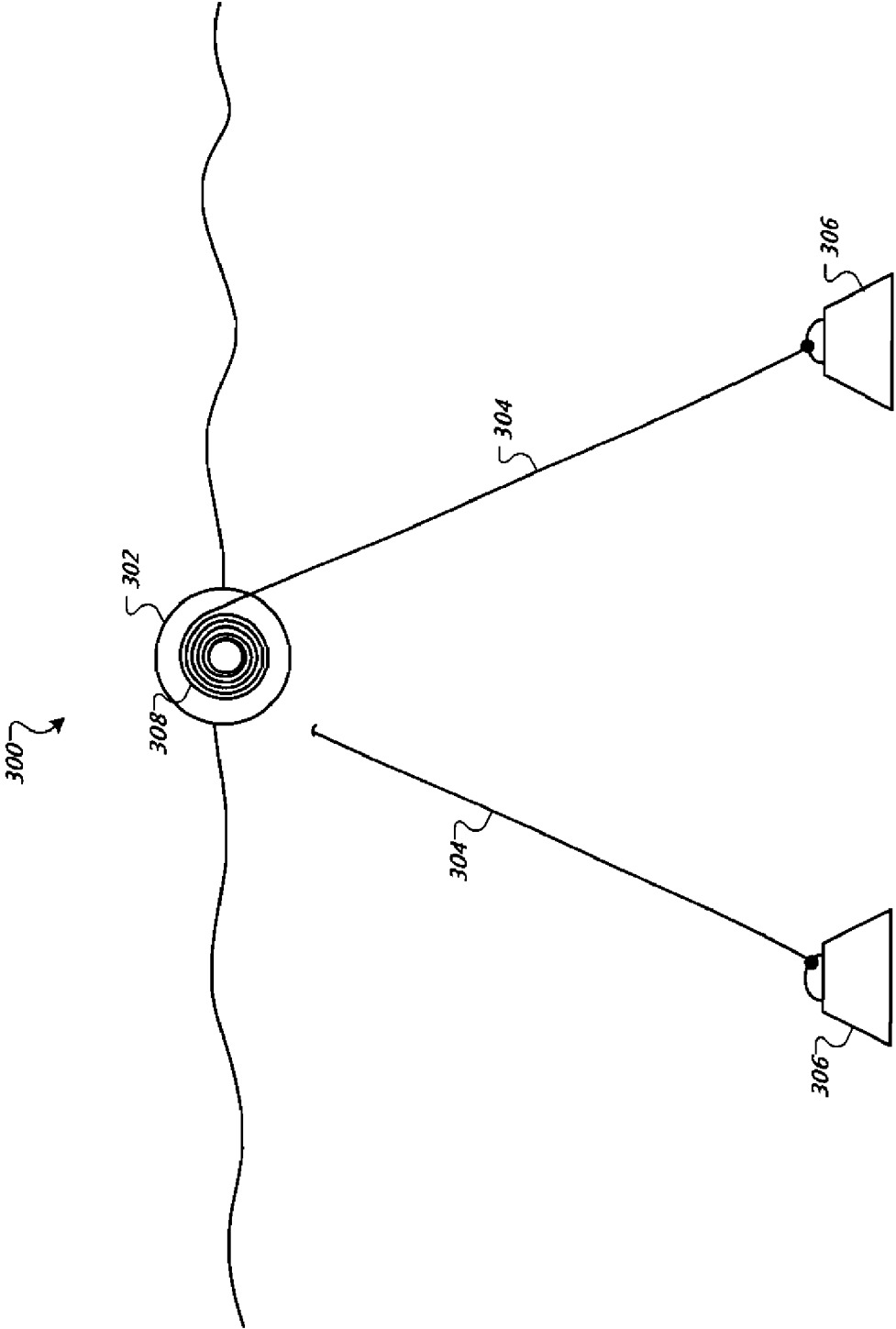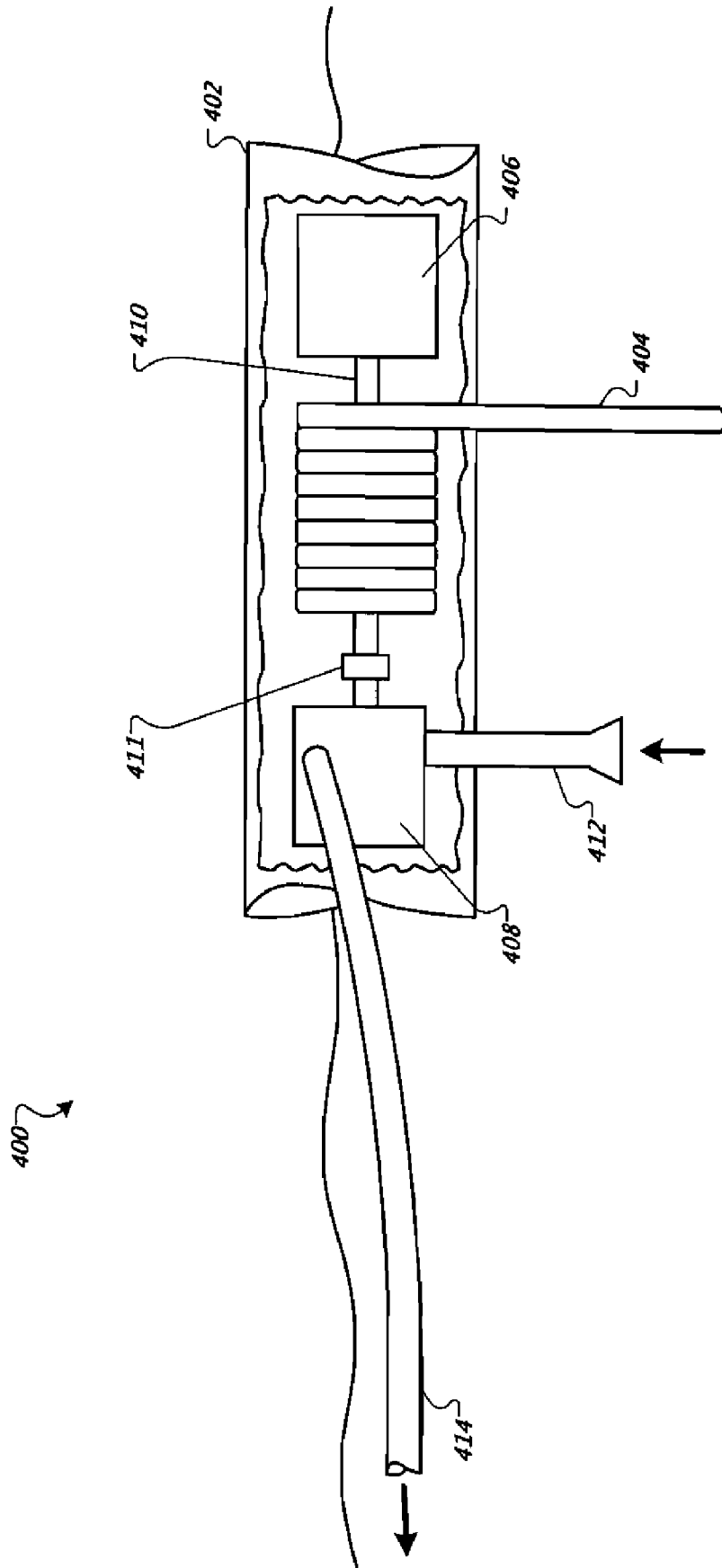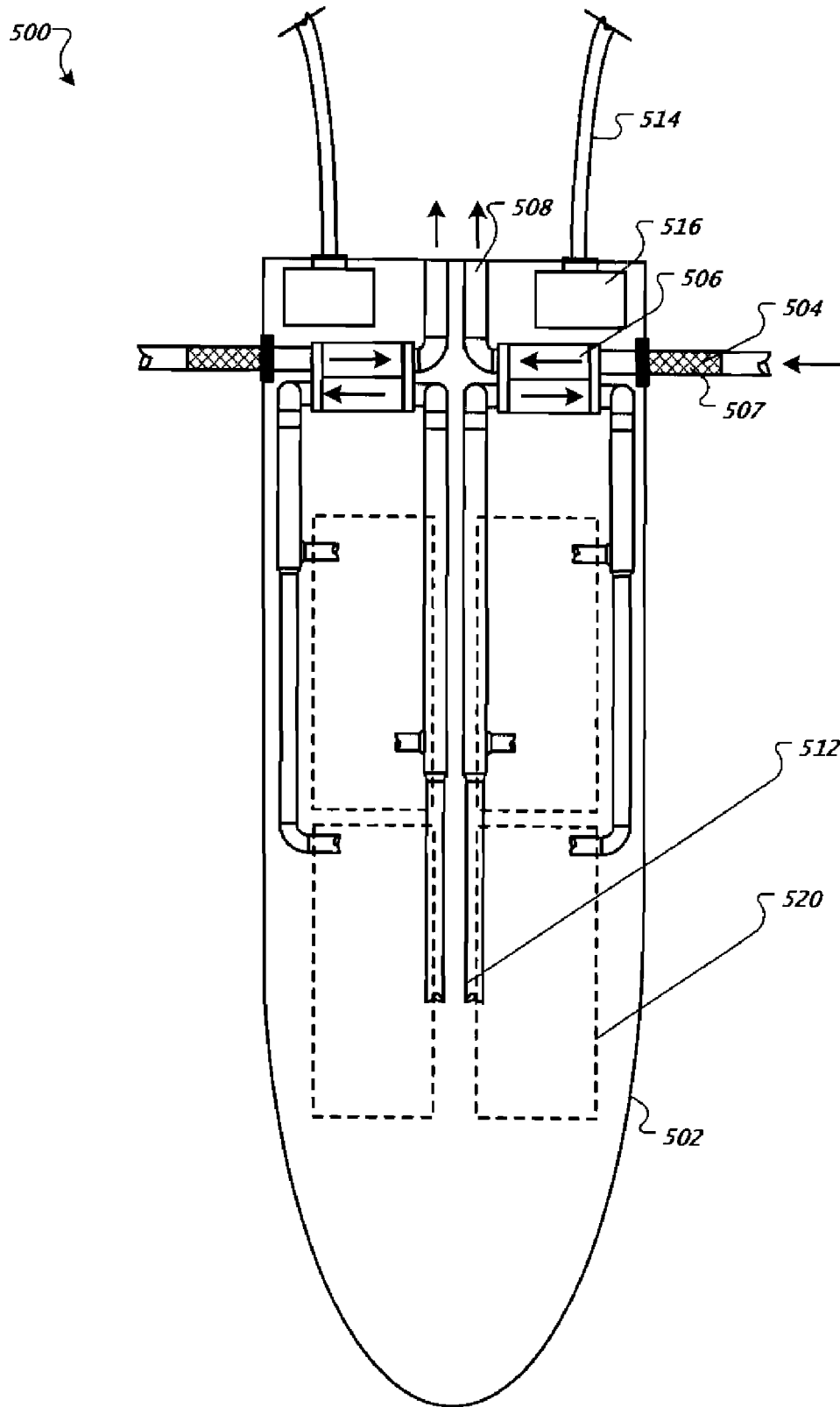
FIG. 5

WATER-BASED DATA CENTER

TECHNICAL FIELD

This document discusses water-based data centers, including systems that may be powered by the motion of water.

BACKGROUND

Public use of the internet continues to grow, with millions of people now accessing the global network. The bandwidth demanded by each of those users also continues to grow substantially—moving from simple e-mails, to graphical web pages, to full streaming video at very high resolutions. In addition, with so-called Web 2.0 applications, more data is needed to support traditional computing applications over the internet. As a result, many information providers are building large computing facilities, known as data centers, that can provide various services to internet users. Sometimes, these data centers can contain thousands of networked computers mounted in a large number of racks.

The internet backbone also needs to grow to support the additional demand from all these new users and new services. Such growth is expensive, however, because backbone routers are huge, complex machines, and running of cross-country fibers costs very much money. In addition, cross-country communication can introduce latency to communications—both because of increased distances, and because of the increased chance of losing and retransmitting packets that are sent through many routers and through long distances.

Thus, it can be beneficial to distribute computing power closer to users. As such, data centers may be moved closer to users, with relevant content sent from a central facility out to regional data centers only once, and further transmissions occurring over shorter regional links. As a result, every request from a user need not result in a transmission cross-country and through the internet backbone—network activity may be more evenly balanced and confined to local areas. Also, transient needs for computing power may arise in a particular area. For example, a military presence may be needed in an area, a natural disaster may bring a need for computing or telecommunication presence in an area until the natural infrastructure can be repaired or rebuilt, and certain events may draw thousands of people who may put a load on the local computing infrastructure. Often, such transient events occur near water, such as a river or an ocean. However, it can be expensive to build and locate data centers, and it is not always easy to find access to necessary (and inexpensive) electrical power, high-bandwidth data connections, and cooling water for such data centers.

SUMMARY

This document describes systems and methods that may be employed to provide data center (e.g., computing, telecommunications, or other similar services) support in an area quickly and flexibly. In general, computing centers are located on a ship or ships, which are then anchored in a water body from which energy from natural motion of the water may be captured, and turned into electricity and/or pumping power for cooling pumps to carry heat away from computers in the data center. In particular examples, the water-powered devices for generating electricity are depicted as so-called Pelamis machines. The data centers may also be on shore and receive power and/or cooling water from floating systems.

In one implementation, a system is disclosed that comprises a floating platform-mounted computer data center

comprising a plurality of computing units, a sea-powered electrical generator in electrical connection with the plurality of computing units, and one or more sea-water cooling units for providing cooling to the plurality of computing units. The computing units may be mounted in a plurality of crane-removable modules. The sea-powered electrical generator may comprise a wave-powered generator system, and may further include a plurality of motion-powered machines arranged in a grid and wired together. The wave-powered electrical generator system may likewise comprise one or more Pelamis machines.

In some aspects, the sea-powered electrical generator may comprise a tide-powered generator system. Also, the cooling units of the system may comprise a plurality of sea-powered pumps and one or more seawater-to-freshwater heat exchangers. In addition, the sea-water cooling units may comprise one or more water-to-water heat exchangers. Moreover, the system may further comprise one or more rectifiers for producing direct current supply power from power supplied by the electrical generator, and the rectifiers may provide power directly to components in the plurality of computing units without further AC-to-DC or DC-to-AC conversion. A plurality of step-down transformers may also be provided to convert the direct current power to a voltage usable by the components in the plurality of computing units.

In another implementation, a method of maintaining a computer data center is disclosed, and comprises generating electrical power using the wave, tidal, or current motion of water adjacent a data center, providing the generated electrical power to the data center, and circulating the water adjacent the data center through a heat exchanger to produce cooling for the data center equipment. The electrical power may be generated by the force of a floating device against moving waves. Also, the data center equipment may comprise a large plurality of computer boards mounted in rack arrays.

In yet another implementation, a system for maintaining a computer data center is disclosed. The system includes a data center located on or near an ocean or ocean extension, a cooling system for providing cooling to the data center using seawater, and a means for providing electrical power for use by the data center.

The details of one or more embodiments are set forth in the accompanying drawings and the description below. Other features, objects, and advantages will be apparent from the description and drawings, and from the claims.

DESCRIPTION OF DRAWINGS

FIG. 1a is a top view of a floating data center system using an array of motion-powered machines.

FIG. 1b is a top view of a floating data center system using a pair of motion-powered machines.

FIG. 1c is a top view of a floating data center system powered by a tidal power system.

FIG. 2 is a side view of a floating data center system.

FIG. 3 is a cross-section of a floating power generation apparatus.

FIG. 4 is a side view of a floating power generation and pumping apparatus.

FIG. 5 is a top view of a floating data center system, showing cooling and electrical components.

Like reference symbols in the various drawings indicate like elements.

DETAILED DESCRIPTION

FIG. 1A shows a top view of a floating data center system **100** using wave-power. In general, the system **100** has a

floating platform and an array of wave-powered generators. The wave-powered generators 106, 110 may be implemented, for example, in the form of Pelamis machines, as discussed in more detail below. The floating platform 102 carries one or more modules of a modular data center 104, which may be powered from electricity produced by the motion of the wave-powered generators 106, and may be cooled by cooling water pumped by the wave-powered generators 110. As a result, the data center modules may operate without being connected to external utilities.

Such an arrangement may beneficially permit for more ready deployment of data centers to areas in particular need of computing or telecommunications power. The data centers may be quickly and inexpensively constructed on land, such as in modular units, including standard shipping containers. They may then be hauled, as shipping containers, on trucks to the seaside, and may then be lifted in conventional manner onto a ship. Once on the ship, they may be connected to electrical and cooling services already on the ship, and the ship may deploy to an area in need of assistance. The ship may then anchor in an area offshore where wave or tidal motion is sufficiently strong or large so as to permit electrical generation and pumping power. In addition, old modules may be easily replaced with newer modules, as new technologies develop or as old units quickly wear out under adverse sea conditions. Moreover, by using standard shipping containers whose transportation is well known to most dock workers and seamen, the system 100 may be more readily transported and implemented without significant or specialized training.

A floating platform 102, such as a cargo ship, may carry one or more modular data centers 104. For example, a freighter may have a data center contained in inter-modal freight containers. Existing mechanisms, such as port facilities, may be used to handle the containers. The platform 102 provides power and cooling capacity to the modular data centers 104, in addition to supporting the modular data centers 104. The modular data centers 104 may be arranged in a two-dimensional or three-dimensional grid. For example, as shown in the figure, two rows that each contain two containers are shown. Those modules could also be stacked two or more high, so that the platform 102 holds eight or twelve or more modules.

Support systems may be provided in the floating platform 102, such as for power and cooling of the modular data centers 104. For example, diesel powered electrical generators may be provided below decks to supply supplemental electrical power such as when high data loads are seen or when the motion-powered machines 106, 110 are otherwise not providing sufficient electricity. Also, pumps and other mechanical components may be provided upon the floating platform 102, and connections between the components and the modular data centers 104 may be provided. The connections may include connectors that terminate on the platform deck near where the data centers 104 are to be located, so that quick-connect connections may be made when the data centers 104 are dropped into location.

Motion-powered machines 106, 110 may provide power and cooling capacity for the platform 102. Motion-powered machines 106, 110 can harness wave energy from a body of water such as the sea or a river, and convert it to a useful form, such as a mechanical motion for powering an electrical generator or for turning or otherwise operating a water pump. One advantage of such a system is that the energy collected from the water is essentially free and non-polluting.

As shown in FIG. 1A, the motion-powered machines 106, 110 are arrayed into two groups, and are formed of multiple Pelamis machines that are described below. Machines 106 are

an array of machines for electrical generation, and are tethered and electrically wired to platform 102. Machines 110 are a pair of machines for pumping of water that is around the platform 102 onto the platform. For example, machines 106 may each create a pumping action that pulls water from their immediate vicinity and pumps it onto the platform 102 through an appropriate conduit.

In general, motion-powered machines 106, 110 may be made up of multiple pontoon segments 106A-D, that are movable relative to each other. One exemplary system is the Pelamis P-750 Wave Energy Converter. The pontoons may take any appropriate size, but may each be on the order of 3.5 meters in diameter 150 meters long. Each machine can generate approximately 750 kilowatts, and an array or farm of machines can produce 2.25 megawatts or more. Approximately 40 machines spread over a square kilometer could also produce approximately 30 MW. The system 100 may operate satisfactorily, for example, approximately 3-7 miles from shore, in 50-70 meters of water.

The pontoons 106A-D are connected end-to-end in a manner (e.g., using joints) that allows them to pivot relative to each other, such as with hinges that allow the motion-powered machines 106, 110 to flex at the pontoon joints. Each individual segment of a machine 106, 110 is connected to the next-adjacent segment with hydraulic cylinders next to the hinges or pivots. For example, each hydraulic piston may be connected to a first pontoon 106A and a second pontoon 106B.

As one pontoon segment pivots relative to another, a hydraulic piston or ram may move into one of the segments to force high pressure oil through hydraulic motors in the segment. The force of the rams may be evened out using hydraulic accumulators attached to the motors, which may operate at, for example, 1500 rpm. The hydraulic motors may in turn be connected via a drive shaft with one or more sealed electrical generators. In sum, relative pivoting of the segments causes the ram to force fluid through the motors, and in turn causes the electrical generators to turn and make electricity. Alternatively, the machines 106, 110 may power water pumps in a similar manner.

The motion-powered machines 106, 110 may be held in place by mooring lines attached to anchors 108. As waves encounter the pontoons, the pontoons may move up or down, bending at the joints to remain at the surface of the waves. Electricity produced by the generators on motion-powered machines 106, 110 may be passed via a conductor, such as a cable, to the floating platform 102.

Electrical power received from the motion-powered machines 106, 110 may be converted to an appropriate form for powering datacenters on the ship. For example, the power may be rectified to produce DC power that may be used directly by computers in modular data centers 104. The generated voltage may also be transformed to one or more appropriate levels. Other portions of the powered may be transformed into an AC waveform of appropriate frequency to operate other items on floating platform 102 that require AC power.

The simple conversion to DC power, without subsequent rebuilding of the power into an AC signal (and subsequently bringing it back to a DC signal at each computer or rack in modular data centers 104) may provide for energy efficiency benefits. Each conversion introduces losses, and because the power can be used in DC form, there is no need to convert and re-convert the signal. Although the varying frequency of the AC signal generally coming from motion-powered machines 106, 110 generally requires rectification and rebuilding of a constant AC signal, because commercial and domestic users

of the electrical demand an AC signal and because transmission over long distances is difficult using DC current, the described single conversion does not require particular AC current, and also does not require transmission over such a distance. Such an approach of converting AC generated at a non-standard frequency to DC without further changes could be used for other natural sources having a changing frequency, such as wind generators on wind farms.

Electricity generated by the motion-powered machines 106 travels through electrical cables (not shown) connected to the platform 102. The electrical cables may run along mooring lines that tie the various motion-powered machines 106 back to the floating platform 102. Alternatively, the electrical cables may run separately from the mooring lines.

The motion-powered machines 106, 110 may be arranged in multiple configurations. Some configuration may be well-suited for maximizing efficiency, while other configurations may be well-suited for survivability, navigation, maintenance, or other purposes. Configurations may trade off several factors, including survivability, efficiency, deployment time, materials required, etc. In FIG. 1A, motion-powered machines 106, 110 are arranged parallel to the heading of the ship and to each other. A standard size for such a system may cover an area approximately 600 m×200 m. Each motion-powered machine may have a pontoon diameter of 3.5 m and length of 35 m. Additional pontoons may be added that increase the overall length of the motion-powered machine.

Some configurations of motion-powered machines may be best suited for efficiently collecting as much energy as possible. For instance, larger arrays may collect more energy than smaller arrays, and larger arrays may be useful where wave activity is not as vigorous as in other locations. Some configurations of motion-powered machines may be well-suited to conditions involving a prevailing weather pattern. For example, motion-powered machines may be oriented so that they are at a particular angle to surface trade winds may harness energy from the waves driven by the trade winds.

Some configurations of motion-powered machines may be best suited to areas with waves that come from many directions. For instance, locations without prevailing winds may have motion-powered machines deployed in a manner that allows them to automatically orient themselves perpendicular to whichever waves are present. In such cases, the motion-powered machines may orient themselves automatically by being tethered at only one end so that the waves pull the motion-powered machine to the most efficient orientation.

Some configurations of motion-powered machines may utilize a layout that maximizes usage of a given space. For example, the motion-powered machines may be laid out in a grid with their anchored points making a honeycomb-shape that allows unhindered operation of all the motion-powered machines with any orientation while at the same time minimizing unused space.

Some configurations of motion-powered machines may be used to minimize required materials. For example, configurations may be used which variously minimize the use of cabling, piping, tethers, anchor points or other equipment. Such configurations may minimize the number of anchor points and tether points that are needed. In some instances, several motion-powered machines may be tethered to the same anchor, thus reducing the number of anchors required. In some instances, motion-powered machines may use the ship as an anchor point. In some instances, several motion-powered machines may be connected together into a group with a single connection with the main ship.

Some configurations of motion-powered machines may be well-suited for surviving storms or other extreme situations.

Certain configurations may be best suited for surviving natural or man-made disasters such as tsunamis or wars. For instance, motion-powered machines which are more submerged than are others may have a higher survival rate when exposed to large waves by "diving" beneath wave crests that might otherwise overstress the motion-powered machines. Installations where each motion-powered machine is connected directly to the platform 102 may reduce the effect of a single set of connections being cut; for instance, if a single motion-powered machine were to be lost, the others may not be affected.

Motion-powered machines may be used in configurations which accommodate other shipping traffic in the area, such as fishing boats, recreational vessels, shipping vessels, etc. Such traffic may be unduly affected by encounters with the array, such as fishing nets tangled with the tethers. Various signaling mechanisms, such as strobing lights, flags, and horns may be used to alert other ships of the existence and location of a particular field of devices.

Some configurations may involve the use of a grid in which each motion-powered machine is connected to multiple other motion-powered machines or the ship in a manner that provides for redundancy in the event a link goes down, e.g. due to failure or maintenance requirements. Such grid connections may occur in the moorings and also in the electrical cables.

Some configurations may be useful for quick deployment, such as towing a string of motion-powered machines that are already attached to the ship and only need to have their anchors attached. Prearranged mooring fields may also be prepared, so that quick connections may be made when the motion-powered machines arrive on-site. Such mooring fields may be prepared while a group of machines is being manufactured and hauled to a site. In addition, the mooring fields may be moved, such as when demand for computing or telecommunications power moves, when sea conditions change (e.g., seasonally) or when a time period for legal occupation of an area expires.

In some implementations, a smaller vessel may be based on the platform 102 which may be used for tending the motion-powered machines. It may perform activities such as site setup, maintenance, or other necessary activities that may require direct interaction with the motion-powered machines. The vessel may include, for example, a smaller boat, e.g., 20-30 feet.

Motion-powered machines of various sizes may be used. In some implementations, large motion-powered machines 106 may be used for electrical generation, whereas small motion-powered machines 110 depicted closer to the boat may be used to pump cooling water to a data center. The generating capacity of a motion-powered machine may be increased by increasing the number of pontoons in a given motion-powered machine.

Configurations may involve motion-powered machines of different sizes. For example, different sized motion-powered machines may be available in the future. In some instances, the motion-powered machines may collect power for performing different functions. For example, some motion-powered machines may be used for generating electricity and other motion-powered machines may be used for pumping water. In some implementations, pumping may be performed by direct mechanical coupling, with pumps located in the motion-powered machines 106, 110. In other implementations, dedicated motion-powered machines generate electricity that is used solely for powering electric pumps.

The platform 102 can be anchored with the motion-powered machines, and/or can carry the machines into location. For example, the motion-powered machines 106, 110 may be

carried aboard or behind the platform or aboard or behind another platform **102** for long distance travel. Upon reaching the destination, the platform **102** may unload the motion-powered machines **106, 110** and set up the array. Equipment, such as a tender or other equipment, may be present on board the platform **102** for unloading and setting up the motion-powered machines **106, 110**. The platform **102** may alternatively unload the motion-powered machines **106, 110** in a nearby port, and the assembled motion-powered machines **106, 110** may be towed by the platform **102** or another vessel to their intended destination.

System **100** may provide for one or more various advantages. For example, much of the world's population lives near oceans, so system **100** could bring computing or telecommunication power close to them. Much of the world's communications infrastructure also runs through the oceans, so that system **100** could tap into existing infrastructure near shorelines. In addition, system **100** may be quickly deployed so as to be inserted in areas requiring quick computing or telecommunication power, such as areas of military conflict or disaster areas.

The data centers **104** may be employed with the computers inside standard shipping containers to make them more portable (e.g., capable of being hauled to the boat or by a truck). The data centers **104** may be constructed modularly in areas having low costs, and may be transported to locations needing communications support relatively quickly. The data centers **104** may be offloaded to areas where a more permanent presence is needed, and may also be connected to the motion-powered machines **106, 110** after such offloading, freeing the ship to deploy to another area. Also, data centers **104**, when in the form of shipping containers, may be quickly traded out when technology changes. Modularization also makes maintenance simpler; hardware that is corroded or worn out from the harsh salt water environment can be easily replaced with fresh hardware by swapping containers.

Use of modules may also provide convenient access to subsystems. Modules may simply be moved to access support structures undergoing maintenance, such as cooling or electrical systems. The modules may be repositioned on the ship temporarily for repairs, or installed in a new location to facilitate continued operation.

The platform **102** may have amenities that support system operations. For instance, the platform **102** may include living accommodations for crew and operating staff. A helipad may also be provided to facilitate access for personnel and quick turn-around for activities such as replacing parts or for setting up new equipment. The platform **102** may, in addition, be able to accommodate a ship tender capable of re-supplying the platform **102** with items such as consumable supplies such as fuel oil and perishables for the crew, parts for maintenance, etc. In addition, out-board fuel tanks may be provided and connected to platform **102** when additional fuel supplies are needed.

The system **100** may include modules with an integral backup power supply and cooling system in the event the primary systems are unavailable. The backup system may be capable of using an alternate source of energy, such as a fuel-based power generation system. In some implementations, the system **100** may be able to store energy to form a reserve that can be drawn upon during periods with low wave activity. As one example, banks of batteries may be used to store electrical energy. As another example, fuel cells may be used with hydrogen kept in a reservoir, which is filled by electrolysis when wave energy is available. Solar power may be used to supplement power collected from the motion-powered machines; calm days where little wave energy may

be available may also be cloudless, maximizing solar energy that is available. The system **100** may be implemented using existing equipment with some modifications. For example, a ship capable of hauling intermodal freight containers may be outfitted with electrical and cooling systems to support the functionality described above.

Electrical and pumping power may also come from devices powered directly by the wind. For example, wind turbines may be mounted or tethered to an ocean floor and provided to receive prevailing winds for power. Such power may be provided instead of, or in supplementation to, water-powered systems. A datacenter may be placed near such wind turbines, which may themselves be arranged in a line or grid arrangement, and be tied electrically to them. In one implementation, power from an array of wind turbines may be provided to a single point connection, and a data center may connect to the power there.

One or more wind turbines may be provided with mechanical linkages that permit them to also pump cooling water to a data center. Such turbines may be dedicated only to pumping, or may provide both electrical generation and pumping. Where pumping is provided, the data center would typically be near the turbine to minimize the length of piping required. In certain implementations, the data center or part of the data center may be attached directly to the turbine, including by being located in the upper head of the turbine that rotates with the turbine blades. In such situations, airflow and turbulence from the blades may be used to help cool the data center.

In addition, cooling may be supplemented by other mechanisms that draw little electricity, such as absorption chillers. Such chillers may be provided on platform **102**, and may be used during periods in which the data center needs to operate and be cooled, but naturally-generated electricity and cooling is insufficient to provide the needed cooling for the data center. In addition, such cooling may be used when pumping power is adequate, but sea water is not sufficiently cool to provide needed levels of cooling.

Where absorption chillers are employed, valving on pipes leading to heat exchangers may be provided to shift one or more heat exchangers from sea-water cooling to chiller cooling. For example, an open loop may exist on a heat exchanger by which sea water flows through one side of the exchanger, and cooling water that enters and leaves the data center flows through the other side. A side branch for the data center cooling water may extend to a heat exchanger whose second side is connected to an absorption chiller. When additional cooling is needed, the data center cooling water may be redirected in whole or in part from the first heat exchanger to the second. Additional heat exchangers may also be employed, so that changes from sea water cooling to chilled water cooling may be made gradually.

FIG. 1B is a top view of a floating data center system **120** using a pair of motion-powered machines. In general, the floating data center system **120** has a floating platform **122** carrying a modular data center **124**. Motion-powered machines **125, 132** may provide power and cooling capacity to floating platform **122**. The floating platform **122** may direct power and cooling capacity supplied by the motion-powered machines to the modular data center **124**. As a result, the floating data center system **120** may be able to operate without external connections for providing power or cooling.

The floating platform **122** may, for example, include a seagoing ship such as a freighter. The modular data center **124** may make use of shipping containers **126**, such as standardized intermodal freight containers, to hold the data center's equipment. The shipping containers **126** may be loaded and unloaded using conventional port equipment. In the event that

one or more modules **126** of the data center **124** needs to be replaced, the floating data center system **120** may simply pull into a port and have the appropriate modules swapped out and replaced with new ones.

The motion-powered machines **125**, **132** may extend laterally from the floating platform **122**, for example, with one end connected to the rear of the floating platform and the other end anchored to the seabed. The motion-powered machines **125**, **132** may gather mechanical power from wave action and apply it to a purpose such as pumping fluids or generating electricity. The relative positioning of the floating platform **122** and the motion-powered machines **125**, **132** is shown here only for illustrative purposes; the actual alignment of the components will generally be established so as to provide for maximum energy generation, and for the proper operation of the platform **122** also.

The motion-powered machines **125**, **132** may have the ability to convert wave action to electricity and pumping capacity. For example, in some implementations, the motion-powered machine **132** may have a piston-powered pump **134** present in its first pontoon **132A**, and electric generators **136** present in its other pontoons **132B**, **132C**, **132D**.

The motion-powered machine may cool the modular data center **124** by pumping coolant. In some cases, the cooling system used in the floating data center system **120** may include an open loop. For example, a conduit **128** may be used to transfer a coolant such as subsurface seawater from a pump **134** located in the first section **132A** of the motion-powered machine **132**, to the floating platform **122**. In some instances, the motion-powered machine **125** may provide electrical power to drive a pump (not shown) onboard the floating platform **122**; the pump may draw in cool seawater through an intake pipe **130** that is used to cool the modular data center **124**. An intake pipe which extends below the surface of the water may draw up cooler water than water that is present at the surface, due to the differences in density between warm and cool water, and due to solar heating of the surface water. Seawater that is pumped into the floating data center **122** may be expelled overboard or underwater as the need arises after it has absorbed heat from the modular data center. Various mechanisms may also be employed to ensure adequate dispersion of the water.

In some instances, the cooling system used in the floating data center system **120** may include a closed loop. For example, a coolant, such as fresh water or ethylene glycol, may circulate between the motion-powered machine **125**, where it is cooled, and the modular data center **124**, where it absorbs excess heat from computing equipment. The conduit **128** may be segregated into separate channels which carry warm and cool coolant. The coolant may be carried to a heat exchanger located in the first pontoon **132A** of the motion-powered machine **132**. The heat may pass from the coolant on one side of the heat exchanger to seawater on the other side of the heat exchanger, thus cooling the coolant before it is pumped back to the floating data center.

In other implementations, a data center may be located on shore, close to a body of water. Power (whether electrical or mechanical) for the data center may be derived from water-based devices such as Pelamis machines of water-based wind generators. The power may then be transmitted to the data center on shore. Cooling water may also be pumped from the body of water to the on-shore data center.

FIG. 1C is a top view of a floating data center system **150** powered by a tidal power system. In general, the tidal power system converts energy gathered from rising and falling tides into electricity. The electricity is passed to the floating data center system **150** where it is used to power and cool computing equipment.

In the figure, a floating data center system **150** includes a floating platform **152** carrying a modular data center **154**. The modular data center **154** may consist of one or more modules on the floating platform. The modules may be, for example, intermodal freight containers. The modules may contain computers and other equipment necessary for data center operations. Such equipment may include computing equipment such as racks of servers or hard drive arrays. The modules may also include communications equipment such as wireless base stations, modems, or any other related equipment. Alternatively, the modules may contain almost exclusive telecommunications equipment, such as switches, routers, and other structures.

A tidal basin **156** provides electrical power to the floating platform **152**. A channel **158** connects the basin **156** to the ocean, and a gate **160** controls the flow of water into and out of the basic **156**. A water-powered generator **162** gathers energy from water flowing in and out of the tidal basin **156**. In operation, the gate **160** may be held open when the tide is rising so that water fills the basin **156**. When the tide peaks, the gate may be closed. When the tide falls, water may be routed from the higher level in the basin **156** through turbines in the water-powered generator, similar in operation to how a dam operates. The gate **160** may also be closed as the tide rises, and higher ocean water may fall through turbines to create power. The gate **160** may thus be operated simply to ensure that the difference in the water height between the basic **156** and the ocean is sufficient to power the generator **162**. The energy collected by the tidal power system may be used to provide electrical power and cooling capacity to the modular data center **154**. As a result, the modular data center **154** may be able to operate using energy gathered from the motion of seawater.

The electricity may be carried to a junction or switching box **164**. The switching box **164** may pass the electricity to the floating platform **152**. When electricity is not available from the tidal basin, such as when the water level inside and outside the tidal basin is (nearly) equal, electricity may be provided from an external source, such a continental power grid **166**. At other times, such as when the modular data center **154** is not at full usage, excess power generated from the tidal basin **156** may be delivered to the power grid **166**. Also, a portion of the power for modular data center **154** may be drawn from generator **162** and a portion from the grid **166**.

Electricity may be passed partway to the floating platform from the switching box via a buried cable **168**. Burying the cable **168** may inhibit damage to it from wave action or beach traffic. At a point **190** away from shore, the cable emerges into the water and is connected to the floating platform **152**, thus supplying it with electricity. In some instances, the cable **168**, or a separate cable, may be used to provide communications between the floating platform and other systems located on shore. The communications cable may include, for example, one or more optical fiber bundles, and may be connected via junction or switching box **164** (which may include both power and data switching components) to an on-shore data network. In some cases, a wireless transceiver on the floating platform may be used for such communication.

FIG. 2 is a side view of a floating data center system **200**. In general, the system **200** has a modular data center **202** aboard a floating platform **204**, connected to one or more motion-powered machines **206**. The modular data center **202** can be made up of computer equipment in one or more modules. The motion-powered machines **206** may provide power and cool-

ing capacity to the modular data center 202. As a result, the modular data centers 202 may function without connecting to external utilities.

A modular data center 202 of a floating data center system 200 has modules 202A, 202B aboard a floating platform 204. The modules 202A, 202B may be in a standardized format, such as an intermodal freight container, such as those used in the transportation industry. The modules 202A, 202B may have computing resources such as racks of servers, telecom equipment, etc.

In some instances, the floating platform 204 may be a ship, such as a freight hauler, outfitted to handle the modular data center 202. The floating platform 204 provides a structure to physically support the modular data center 202 as well as utilities such as electricity and cooling capacity. The floating data center 204 may be connected to an external power generating device such as a motion-powered machine 206. The motion-powered machine 206 may in turn harness wave energy to provide resources such as power or cooling capacity to the modular data center 202. The modular data center 202 may use power supplied to the floating platform 204 by the motion-powered machines 206. The connection between the floating platform 204 and the motion-powered machine 206 may be in the form of a cable 208, for example, when electricity is being supplied. If cooling capacity is being supplied, other appropriate connectors, such as a flexible tube may also be used.

Power may be supplied to the floating platform 204 using standard techniques for transferring marine power. Electricity may be generated by the motion-powered machine 206 at an appropriate voltage and passed through the cable 208 to the floating platform 204. For example, a high-voltage AC electrical system may be used with a step-up transformer located in the motion-powered machine 206 and a step-down transformer located in the floating platform 204.

The electricity may be passed through a power converter 224 and be distributed to various systems, such as a pump 216 or data center modules 202A, 202B. Power lines 220 within the ship 204 may distribute electricity to the modular data centers 202A, 202B. In some instances, the power converter 224 may output several different voltages. For example, it may output 120V AC 60 Hz for electronics designed for the North American power grid and 240V AC 50 Hz for electronics designed for European power grids. DC power may also or alternatively be provided, for example, for certain server racks that do not use switching power supplies.

Cool water is denser than warm water, causing water below the surface to be cooler than water at or near the surface. To take advantage of this, the cool water may be drawn through an inlet tube 210 that extends below the surface. Pump 216 may be used to draw in the cool water and send it through supply pipes 218 for distribution to the modules 202A, 202B. The cool water may also pass through heat exchangers (not shown) either at or away from the data center modules. Such use of heat exchangers allows the relatively caustic seawater to be isolated in only one part of the system, with fresh water or other coolant circulating in a closed-loop system on the other side of the heat exchangers. As a result, maintenance may be minimized, as the closed-loop side of the system may be kept in operation, with frequent replacements needed only on the saltwater side of the system.

The heat exchangers may be connected to integrated cooling systems within the modules 202A, 202B that directly cool equipment. The cool water warms up as it absorbs waste heat deposited in the heat exchangers, for instance, by computer equipment. The warm water may pass through return pipes

220 and be expelled, for example, through a port 214 in the rear of the floating platform 204.

The floating platform 204 may have integrated control systems for handling power and cooling. For example, the floating platform 204 may have power monitoring equipment that automatically brings on additional sources of power, such as other motion-powered machines or backup generators, as the load demanded by the modular data center 202 increases. An automatic control system, which may be housed with power converter 224 and may be controlled from the deck of the floating platform 204 or other appropriate area (such as by distributed controls in each of the modules 202A, 202B), may be used to adjust cooling capacity to an optimum level that provides sufficient cooling without excessive wear and tear on moving parts. For example, in some implementations, temperature sensors integrated with the supply 218 and return 220 pipes may be used to determine whether the current flow rate is sufficient to keep the modular data center cool. In some implementations, the modules 202A, 202B may have sensing and control systems that are integrated with the floating platform 204 such that they request additional cooling capacity when needed.

FIG. 3 is a cross-section of a floating power-generation apparatus. The illustrated apparatus is different from the Pelamis machines discussed above. In general, a floating body 302 has tethers 304 attached to anchors 306. The tethers 304 may be wrapped around a spring-loaded hub 308 so that the tethers 304 pull out when the waves are high and spring back when the waves are low. The resulting motion may be converted by a generator to electricity, or may be used to operate a mechanical pump for pumping of seawater to a floating platform for cooling.

In more detail, similarly to the motion-powered machines described above, a floating body 302 may be attached with tethers to anchors 306 on a seabed. In this case, however, the tethers 304 may be wrapped around a spring-loaded hub 308, so that the tethers 304 pull out when the waves are high, due to the body's 302 flotation, and springs back when the waves are low. A mechanism, such as a ratchet, may transfer the back-and-forth motion to a shaft. The resulting rotation of the shaft can be transmitted, in some cases, to a electrical generator; electricity produced in such a manner may be transferred, for instance, to a boat for powering computers or other electronic equipment. Such a mechanism may be used as an alternative or additional power generating mechanism to the Pelamis machines described above.

The back-and-forth motion of the tether 304 may also be used to drive a pump used for pumping seawater to a boat for cooling. In some cases, the back and forth motion may be converted to rotary motion for use in driving a rotary pump. In other cases, the back and forth motion may be used to drive a piston pump. In some cases, multiple tethers, springs, or hubs may be used, and dual ratchets may be employed with a stiff tether to permit gathering energy in wave troughs and crests. In some instances, the tethers may be used to transfer electricity or coolant first to the anchor, then to the boat. In other cases, the generator or pump may be co-located with the anchor instead of the floating body 302.

FIG. 4 is a side view of a floating power generation and pumping apparatus 400, like that depicted in FIG. 3. In general, the apparatus may have a floating body 402, a tether 404, a generator 406, and a pump 408. The tether 404 may be wrapped around a spring-loaded shaft 410 which connects to the generator 406 and pump 408. Motion caused by the coiling and uncoiling of the tether 404 may provide force for rotating the shaft 410 and operating the generator 406 and pump 408.

The apparatus **400** has a floating body **402** with positive buoyancy. The floating body **402** may include, for instance, a sealed steel tube of substantial (e.g., 3.5 meters) diameter and length (e.g., 10-30 meters). An attached tether **404** may anchor the apparatus **400** to the seabed. A generator **406** for generating electricity may be located inside the body **402**, and may be connected to the rotating of the tether **404** by a shaft **410**. The body **402** may also house a pump **408**, such as various forms of rotary pumps. The apparatus **400** may be used, for instance, to provide electrical power and cooling capacity to a floating data center.

The tether **404** may have one end attached to an anchor on the seafloor and the other end wrapped around a spring-loaded shaft **410**. As waves strike the apparatus, its buoyancy causes it to move up and down, imparting a spinning motion on the shaft **410**. The spinning shaft may cause the pump **408** to pump water and the generator **406** to generate electricity. The pump **410** may suck seawater in through an intake pipe **412** and send it through a tube **414** to a nearby boat, for instance, to cool a floating data center. In some implementations, the tether **404** may also include an electrical conductor used for transmitting electricity to a load. For example, electricity may be delivered through the conductor to a nearby ship-based or shore installation.

In some implementations, a transmission **411** may be used to control rotation of the pump **408** and/or generator **406**. Such control may permit an operator to decrease or increase the amount of water flow, and to thereby match water flow to the cooling needs of the system, and/or to allocate the power between the pump **408** and generator **406**. In some implementations, the transmission **411** may be controlled electronically, as it may be desirable to remotely control the transmission of the apparatus. In some cases, the transmission may engage the generator, causing it to generate electricity. In other cases, the transmission may engage the pump, causing it to pump water as the shaft is rotated.

FIG. **5** is a top view of a floating data center system **500**, showing cooling and electrical components. In general, the system **500** shows a below-decks view of various components used to serve an overhead modular data center. The modular data center may be made up of several modules **520** filled with computing equipment cooled by a closed-loop cooling system.

The floating data center system **500** may be carried by a ship **502**. Cool seawater may flow into an on-board cooling system via tubes **504** from an external source, such as the motion-powered machines described above or from intakes that open into the sea. Heat exchangers **506** transfer heat from a closed-loop cooling system to the seawater on an open-loop side of the system **500** before it is expelled overboard through ports **508** at the rear of the ship **502**. The tubes (or other conduits) may be connected to the ship **502** via flexible connectors **507**, which may permit for relative motion between the ship **502** and the tubes **504**.

The on-board cooling system may be a closed-loop system that transfers heat using coolant flowing through a network of pipes **512**. Use of a closed-loop system allows the use of a coolant less corrosive than the seawater that is ultimately used as a heat sink. The heat exchanger **506** may be exposed to seawater on one side and to the closed loop cooling system on the other. In some cases, the heat exchanger **506** may be of a design, such as a plate heat exchanger, which allows relatively easy replacement of parts subject to failure, such as surfaces exposed to the seawater flowing through them. The portions of the heat exchanger **506** that require replacement may be much smaller and thus may be removed and replaced more easily than the entire system.

Cables **514** may supply electricity to power converters **516** from devices such as motion-powered machines. The power converters **516** convert and condition the supplied power to a suitable form for distribution to data center modules **520** located in the ship **502**.

In some implementations, electrical power may be distributed such that modules **520** located in different portions of the ship are powered independently. For example, modules on the port side of the ship may be powered by one set of motion-powered machines and modules on the starboard side of the ship may be powered by another set of motion-powered machines. In such a case, it may be possible to have a limited deployment of motion-powered machines to power a portion of the modular data center. The system may be configured so that power may be transferred from one portion to another. For example, data modules in one portion may experience a peak demand that exceeds the power available form their assigned motion-powered machines; in such a situation, the power supplied to them may supplemented with power provided by motion-powered machines that provide power to other data modules.

Also, the power converters **516** may provide the power in various forms as needed on the ship. For example, as noted above, the power may be provided at various voltages and frequencies of AC power. Also, the power coming in from cables **514**, such as AC power at one or more frequencies associate with generators on water-powered machines, may simply be broken down to DC power at one or more voltages for powering the data centers and other components on the ship.

A number of embodiments have been described. Nevertheless, it will be understood that various modifications may be made. For example, although much of the discussion here has centered around wave-powered machines, other power mechanisms, such as wind power (e.g., from sea-based wind generator farms) and river current power may also be used. Also, although several applications of the systems and methods have been described, it should be recognized that numerous other applications are contemplated. Accordingly, other embodiments are within the scope of the following claims.

What is claimed is:

1. A system, comprising:
   a computer data center proximate to a body of water comprising a plurality of computing units;
   a sea-based electrical generator in electrical connection with the plurality of computing units; and
   one or more sea-water cooling units for providing cooling to the plurality of computing units.

2. The system of claim **1**, wherein the computing units are mounted in a plurality of crane-removable modules.

3. The system of claim **1**, wherein the sea-based electrical generator comprises a wave-powered generator system.

4. The system of claim **3**, wherein the sea-based electrical generator comprises a plurality of motion-powered machines arranged in a grid and wired together.

5. The system of claim **4**, wherein the wave-powered electrical generator system comprises one or more Pelamis machines.

6. The system of claim **1**, wherein the sea-based electrical generator comprises a tide-powered generator system.

7. The system of claim **1**, wherein the cooling units comprise a plurality of sea-powered pumps and one or more seawater-to-freshwater heat exchangers.

8. The system of claim **1**, wherein the sea-water cooling units comprise one or more water-to-water heat exchangers.

9. The system of claim **1**, further comprising one or more rectifiers for producing direct current supply power from power supplied by the electrical generator.

10. The system of claim **9**, wherein the rectifiers provide power directly to components in the plurality of computing units without further DC-to-AC conversion of the power.

11. The system of claim **10**, further comprising a plurality of step-down transformers to convert the direct current power to a voltage usable by the components in the plurality of computing units.

12. The system of claim **1**, wherein the sea-based electrical generator comprises one or more wind turbines.

13. The system of claim **12**, wherein the one or more wind turbines provide pumping power for the sea-water cooling units.

14. The system of claim **1**, further comprising a supplemental chiller cooling system on a platform with the data center to provide additional cooling when the one or more sea-water cooling units is insufficient.

15. The system of claim **1**, wherein the computer data center comprises a floating-platform mounted data center.

16. A method of maintaining a computer data center, comprising:

generating electrical power using the wave, tidal, or current motion of water adjacent a data center;

providing the generated electrical power to the data center; and

circulating the water adjacent the data center through a heat exchanger to produce cooling for the data center equipment.

17. The system of claim **16**, wherein the electrical power is generated by the force of a floating device against moving waves.

18. The system of claim **16**, wherein the on-board or on-shore data center equipment comprises a large plurality of computer boards mounted in rack arrays.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 7,525,207 B2   Page 1 of 1
APPLICATION NO. : 11/679013
DATED : April 28, 2009
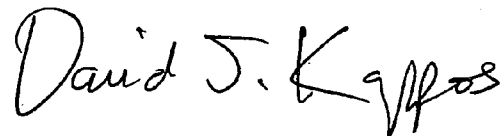INVENTOR(S) : Jimmy Clidaras, David W. Stiver and William Hamburgen

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the Title Pg. Item (56), line 9, Other Publications, delete "waqve" and insert -- Wave, --, therefor.

Signed and Sealed this

Fifteenth Day of September, 2009

David J. Kappos
Director of the United States Patent and Trademark Office