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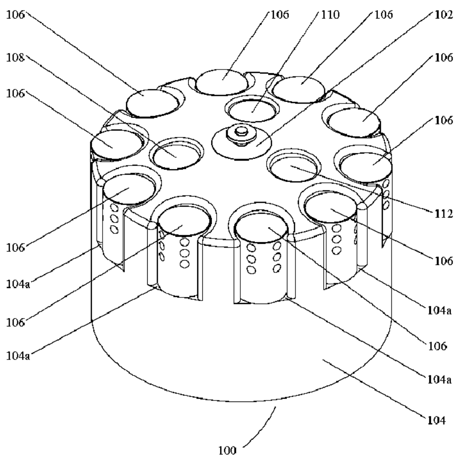
(54) Title **Node Hub – a seismic reservoir monitoring system for deployment on the seafloor in marine seismic surveys, and a method for deployment of seismic sensor nodes on the seafloor and collecting the seismic sensor nodes.**

(57) Abstract

A sensor system for deployment on the seafloor in marine seismic surveys includes a hub, a seismic base station on the hub, and a plurality of seismic sensor nodes that are mounted outside of the seismic base station in base units. The system further includes recording electronics, a memory for storing seismic data and a battery for providing power for an extended period in the surveys. Further, a method of deploying a sensor system on the seafloor by an ROV, the seismic sensor nodes are detached from the seismic base station by the ROV's manipulator arm and positioned at their respective recording positions.



Node Hub – a semi-permanent seismic reservoir monitoring system

Background of the Invention

The present invention relates to seismic reservoir monitoring system for use in conducting marine seismic surveys.

The conventional seismic systems and methods that are used to monitor fluid changes in petroleum reservoirs are either by using time lapsed 3D streamer surveys or by using permanent electric or optical ocean bottom cables (OBC) that are buried in the sea bottom. In the marine seismic surveys, two types of seismic waves are of interest, pressure waves (P-waves) and shear waves (S-waves). The drawback with streamer surveys is that they only record pressure waves (P-waves) and not shear waves (S-waves). Further, data recorded by streamers are more likely to contain more sea-state induced noise, and when repeating the surveys the actual positioning of the towed streamers is difficult to repeat from survey to survey. The OBC cables record both P-waves and S-waves and their receiver positions are in the exact position over time making the repeat surveys to be very accurate. However, the installation of these permanent systems are very expensive and there is also a problem that the hardware installed (sensors, electronics, cables for transmitting power and signals to and back from the receivers) are likely to fail over time. Aging problems have been experienced for hardware such as geophones and hydrophones. At every receiver, there are also cable terminations that must be watertight and not leak over time. The systems should be fully functional for 10-15 years or more and it is very costly to repair when/if the equipment is failing on the seafloor.

U.S. Patent application no.15/212,428 discloses an integrated adhesive sensor array includes an adhesive a patch, a sensor hub, and a detachable sensor pod packaged as a unit.

U.S. Patent application no.14/774,544 discloses a plurality of sensor nodes may be placed along each of one or more ocean bottom cable assemblies (OBCs). The OBCs is coupled to a respective hub device and the hubs are configured to float on the surface of the water column.

U.S. Patent application no.14/774,369 discloses an ocean bottom cable comprising a plurality of sensor nodes for collecting seismic data may be coupled to a submerged hub. The submerged hub may provide seismic data storage, power, clock, and other support for operating the sensor nodes.

U.S. Patent application no.15/309,007 discloses an ocean bottom cable comprising a plurality of sensor nodes, and a hub device coupled to the ocean bottom cable, wherein the hub device is positioned at or near a predefined location below the water surface.

PCT application no. PCT/NO2015/050197 discloses ocean bottom seismic data acquisition systems for conserving power while conducting an ocean bottom seismic survey. Sensor nodes placed on seafloor may be configured to operate in at least an idle mode and an active mode.

As an alternative to the systems and methods described above, autonomous seismic nodes have also been used. The autonomous seismic nodes are deployed on the seafloor and can be positioned very accurately. Once the data is acquired, the nodes are recovered by ROV and the data can subsequently be downloaded on the vessel. However, using standalone nodes for time lapsed surveys means that a vessel with working class ROV must be mobilized for every survey. The number of nodes required depends on the size of the survey area and the spatial sampling required on the seafloor but normally the number of nodes can be from a couple of hundred to several thousand per survey. Each node also needs to have enough battery power to allow for the necessary recording time. And this makes them relatively big in size. There has also been some concern among oil companies that even if the nodes can be re-positioned with centimetre accuracy on the seafloor the seismic coupling to the seafloor could change between each survey and that can result in a degradation of the time lapsed data set's.

Therefore, there is a need for a new approach for conducting marine seismic surveys which can lower the cost for time lapsed monitoring surveys and increase the effectiveness in positioning of nodes on the seafloor by a node hub deployed by a Remotely operated vehicle (ROV) or autonomous underwater vehicle (AUV).

Summary of the invention

In particular, the invention provides a system and methods for conducting marine seismic surveys which can lower the cost for time lapsed monitoring surveys and increase the effectiveness in positioning of seismic nodes on the seafloor that are deployed by a Remotely Operated Vehicle (ROV).

In one embodiment, the present invention provides a sensor system for deployment on the seafloor in marine seismic surveys. The sensor system comprises of a hub, a seismic base station on the hub, and a plurality of seismic sensor nodes that are mounted outside of the seismic base station. The seismic base station contains recording electronics, a memory for storing seismic data and a battery for providing power for an extended period during the surveys. When the sensor system is deployed on the seafloor by a ROV, the seismic sensor nodes are detached from the seismic base station by the ROV's manipulator arm, and moved and positioned at their respective recording positions. The seismic sensor nodes are attached to seismic base station with a thin cable that can contain an optical fibre and/or an electrical conductor for transmitting electrical power to the seismic sensor nodes and to transmit the recorded signals back to the seismic base station.

Further, the seismic base station includes electronics but not limited to an acoustic modem, an optical modem or any wireless receivers which is configured for underwater communication and transmitting the recorded seismic data. The seismic base station also comprises of an integrated navigation transponder for positioning seismic sensor nodes on the seafloor.

The seismic base station is activated before each survey and starts the recording of the seismic data. The seismic base station is configured to operate in sleep mode to save power; also the seismic base station is configured to operate in the sleep mode between each survey. The sleep mode operates the seismic base station in a low power mode and shutting off power to the seismic sensor nodes. The seismic base station will have a very accurate oscillator typically a chip scale atomic clock. This oscillator needs to be regularly calibrated and this can be done at the time when the seismic base station is activated by using an optical or acoustic signal or the calibration can be done by physical connection.

In another embodiment, the present invention provides a much lower cost over time compared to the use of standalone autonomous nodes that must be deployed and recovered for each survey. When compared to traditional autonomous nodes that are left on the sea floor between each survey, the power consumption per receiver position will be significantly lower since only the seismic base station will contain batteries and all main recording electronics etc. will be centralised in the base station. The seismic sensor nodes will not consume any power between each survey since they will receive power from the base station during recording. If each seismic base station is connected to, for example nine seismic sensor nodes that are each placed in a receiver position, then the effort for activation and data harvesting will be reduced by a factor of nine.

In another embodiment, the seismic base station can have one or more "spare seismic sensor nodes" for redundancy such that if any of the seismic sensor nodes would fail over time, then a spare can be used to replace the failing one. The upfront cost for such system will be much lower than for a permanent installed electrical OBC system. And the cost to replace any part if it fails over time will also be much lower.

In one another embodiment, the invention provides a method for deployment of seismic sensor nodes on the seafloor and collecting the seismic sensor nodes used in a marine seismic survey, the method includes deploying a sensor system comprising a hub, a seismic base station on the hub, and a plurality of seismic sensor nodes are mounted outside of the seismic base station, causing the sensor system to ascend through the water towards the seafloor by a Remotely Operated Vehicle (ROV), detaching the seismic sensor nodes from the seismic base station by the ROV's manipulator arm, and move or position at recording positions on the seafloor and recoding the seismic data on the seafloor. Further, the recorded seismic data from the seismic sensor nodes are transmitted back to the seismic base station and after each survey the recorded seismic data will be harvested by a dedicated small fast moving ROV or, for example, or by an AUV that moves from one seismic base station to another seismic base station collecting the data.

Further in another embodiment of the present invention there is provided a method of deploying seismic sensor nodes on the seafloor at their respective recording positions and collecting seismic sensor nodes used in a marine seismic survey back to seismic base station by using ROV's manipulator arm.

Again in another embodiment of the present invention there is provided a method of deploying seismic sensor nodes on the seafloor at their respective recording positions by an integrated navigation transponder, integrated navigation transponder may include estimating the positioning at seafloor. Further, the integrated navigation transponder may manoeuvre the ROV to move approximately at the respective recording positions.

The seismic base station will have a very accurate oscillator typically a chip scale atomic clock. This oscillator needs to be regularly calibrated and this can be done at the time when the seismic base station is activated by using an optical or acoustic signal or the calibration can be done by physical connection.

As described above, the system comprises recording electronics, a memory for storing seismic data and a battery for providing power for an extended period in the surveys. The recording electronics may contain an acoustic modem, an optical modem or any wireless receivers located within the seismic base station, the recording electronics being electrically coupled to each of the seismic sensor node in order to receive seismic data therefrom. Alternatively, the system may comprise a data recorder, and optionally a clock, co-located with each seismic sensor node.

Brief description of the Drawings

The present disclosure may be better understood by reference to one or more of these drawings in combination with the detailed description presented herein;

Fig.1 illustrates seismic sensor system in accordance with various implementations of the present disclosure;

Fig.2 illustrates seismic sensor system in deploying configuration in accordance to with various implementations of the present disclosure;

Fig.3 illustrates seismic sensor system in another deploying configuration in accordance to with various implementations of the present disclosure;

Fig.4 illustrates seismic sensor system in another deploying in spider configuration in accordance to with various implementations of the present disclosure; and

Fig.5 illustrates a method of deploying seismic sensor system in an exemplary configuration of seismic surveys in accordance to with various implementations of the present disclosure.

Detailed description of the Invention

In the following description, numerous details are set forth to provide an understanding of the present disclosure. However, it will be understood by those skilled in the art that the present disclosure may be practiced without these details and that numerous variations or modifications from the described embodiments are possible.

The present invention provides a system and methods for conducting marine seismic surveys that can lower the cost for time lapsed monitoring surveys and increase the effectiveness in positioning of seismic sensor nodes on the seafloor. It will be appreciated by the person with skill in the art that the use of node hub deployed by a Remotely Operated Vehicle (ROV) in marine seismic surveys is very desirable as it allows both S and P wave data to be collected with relatively high signal-to-noise ratio.

The invention will be explained with reference to the drawings. Fig.1 illustrates overview of a sensor system 100 of the present invention. In one embodiment, the sensor system 100 for deployment on the seafloor in marine seismic surveys comprises a hub 102, a seismic base station 104 on the hub 102, and a plurality of seismic sensor nodes 106 are mounted outside of the seismic base station 104 in the base unit 104a. The seismic base station 104 contains recording electronics 108, a memory 110 for storing seismic data and a battery 112 for providing power for an extended period in the surveys. When the sensor system 100 is deployed on the seafloor by the ROV, the seismic sensor nodes 106 are detached from the seismic base station 104 by the ROV's manipulator arm and moved and positioned at their respective recording positions. As shown in Fig.2, the seismic sensor nodes 106 are attached to the seismic base station 104 with a thin cable 114 that can contain an optical fibre and/or an electrical conductor for transmitting electrical power to the seismic sensor nodes 106 and for transmitting the recorded signals back to the seismic base station 104.

As shown in Fig.1 and Fig.2, there are ten seismic sensor nodes 106 are individually placed in the base unit 104a on the seismic base station 104. The seismic base station 104 can have one or more "spare seismic sensor nodes" for redundancy such that if any of the seismic sensor nodes would fail over time, then a spare can be used to replace the failing one. The upfront cost for such a system will be much lower than for a permanent installed electrical OBC system. And the cost to replace any part if it fails over time will also be much lower.

In one embodiment, the seismic base station 104 includes recording electronics 108 but not limited to an acoustic modem, an optical modem or any wireless receivers which is configured for underwater communication and transmitting the recorded seismic data. In an alternate embodiment, transmitting the recorded seismic data from the seismic sensor nodes 106 back to the seismic base station 104 is by using an acoustic transponder. The seismic base station 104 also comprises an integrated navigation transponder for positioning seismic sensor nodes 106 on the seafloor.

In one another embodiment, the invention provides a method for deployment of seismic sensor nodes 106 on the seafloor and collecting the seismic sensor nodes 106 used in a marine seismic survey, the method includes deploying a sensor system 100 on the seafloor, causing the sensor system 100 to ascend through the water towards the seafloor by a Remotely Operated Vehicle (ROV), detaching the seismic sensor nodes 104 from the base unit 104a by the ROV's manipulator arm, and moved or positioned at recording positions on the seafloor and recoding the seismic data on the seafloor . Further, transmitting the recorded seismic data from the seismic sensor nodes 106 back to the seismic base station 104 and after each survey the recorded seismic data will be harvested by a dedicated small fast moving ROV or for example, by an AUV that moves from one seismic base station 102 to another seismic base station 102 collecting the data.

In a preferred embodiment, there are ten seismic sensor nodes 106 (Nine seismic sensor nodes 106 are active and One seismic sensor node 106 is spare) that are arranged on the seismic base station. In a preferred embodiment the size of the seismic sensor node 106 is 16× 8 cm. In a preferred embodiment the size of the sensor system is 1m in diameter and 70 cm in height. In a preferred embodiment, there are up to 340 battery cells 112 that are integrated with the seismic base station 106.

During marine seismic surveys, the seismic base station 102 is activated before each survey and starts the recording of the seismic data. The seismic base station 104 is configured to operate in the sleep mode to save power, further the seismic base station 104 is configured to operate in the sleep mode between each survey. The sleep mode operates the seismic base station 104 in a low power mode and shutting off power to the seismic sensor nodes 106 when surveying is stopped. The seismic base station 104 will have a very accurate oscillator typically a chip scale atomic clock. This oscillator needs to be regularly calibrated and this can be done at the time when the seismic base station 104 is activated by using an optical or acoustic signal or the calibration can be done by physical connection.

Fig.3 shows the sensor system 100 in deploying configuration, the seismic sensor nodes 106 are positioned at their respective recording positions via the thin cable 114. Accordingly, the seismic sensor nodes 106 are attached to seismic base station 104 with the thin cable that transmits electrical power to the seismic sensor nodes 106 and again transmits the recorded signals back to the seismic base station 104. The seismic sensor nodes 106 are positioned on the seafloor by the thin cable 114 from the seismic base station 104 with distance of typically 100-400 meters.

Fig.4 shows the sensor system 100 deploying in spider configuration, wherein the seismic sensor nodes 106 are attached to the seismic base station 104 with the thin cable 114. In one embodiment, the thin cable 114 is 2x optical fibre and 2x copper wire. The seismic base station 106 is connected to for example nine seismic sensor nodes 106 that are each placed in a receiver position, in this arrangement the effort for activation and data harvesting will be reduced by a factor of nine.

In an exemplary method as shown in Fig.5, there are multiple sensor system 100 that can be deployed in a seismic survey. For illustrative purpose, in one embodiment there are eight seismic sensor system 100 that are been deployed on the seafloor in the configuration of four seismic sensor system 100 in each side. The approx. receiver area covered in the survey is 10 sqkm.

This provides a much lower cost over time compared to the use of standalone autonomous nodes that must be deployed and recovered for each survey. When compared to traditional autonomous nodes that are left on the sea floor between each survey, the power consumption per receiver position will be significantly lower since only the seismic base station 104 will contain batteries 112 and all recording electronics 108 etc. will be centralised in the seismic base station 104. The seismic sensor nodes 106 will not consume any power between each survey since they will receive power from the seismic base station 104 during recording.

Further, this will lower the cost for time lapsed monitoring surveys as each seismic sensor node 106 comprises one hydrophone and three orthogonal geophones x, y, z (not shown in drawings). This geometrical distribution allows the seismic sensor nodes 106 to settle on the seafloor once the sensor system 100 is fully deployed, whilst of course retaining the seismic sensor nodes 106 within the sensor system 100 during the deployment procedure. This contact with the seafloor is important as it allows data associated with both P and S waves to be collected by the sensor system 100. The sensor system 100 will be deployed by an ROV before the first survey and then be left on the seafloor between the different repeat surveys.

It should be apparent to persons skilled in the arts that various modifications and adaptation of this structure described above are possible without departure from the spirit of the invention the scope of which is defined in the appended claim.

Claims:

1. A sensor system 100 for deployment on the seafloor in marine seismic surveys, comprising:
a hub 102;
a seismic base station 104 on the hub 102; and
a plurality of seismic sensor nodes 106 that are mounted outside of the seismic base station 104 in the base unit 104a,
characterized in that the seismic base station 104 comprises recording electronics 108, a memory 110 for storing seismic data and a battery 112 for providing power for an extended period in the surveys,
characterized in that the sensor system 100 is being deployed on the seafloor by a Remotely Operated Vehicle (ROV), and
characterized in that the seismic sensor nodes 106 are detached from the seismic base station 104 by the ROV's manipulator arm and positioned at recording positions on the seafloor.

2. The sensor system 102 of claim 1, **characterized in that** the seismic sensor nodes 106 are placed into the base unit 104a on the seismic base station 104 with a thin cable 114, the thin cable 114 contains an optical fibre and/or an electrical conductor for transmitting electrical power to the seismic sensor nodes 106 and again transmitting the recorded seismic data back to the seismic base station 104.

3. The sensor system of claim 1, **characterized in that** the seismic base station 104 is configured for underwater communication and transmitting the recorded seismic data.

4. The sensor system of claim 1, **characterized in that** further transmitting the recorded seismic data back to the seismic base station 104 is by using an acoustic transponder.

5. The sensor system of claim 1, **characterized in that** the seismic base station 104 further comprises an integrated navigation transponder for positioning seismic sensor nodes 106 on the seafloor.

6. The sensor system of claim 1, **characterized in that** the recording electronics 108 comprises but not limited to an acoustic modem, an optical modem or any wireless receivers.

7. The sensor system of claim 1, **characterized in that** the seismic base station further comprises an oscillator that is a chip scale atomic clock.

8. The sensor system of claim 1, **characterized in that** the seismic base station 104 is activated before each survey and starts recording the seismic data on the seafloor.

9. The sensor system of claim 1, **characterized in that** the seismic base station 104 is configured to operate the seismic sensor nodes 106 in sleep mode to save power or the seismic base station 104 is configured to operate in the sleep mode between each survey.

10. The sensor system of claim 9, **characterized in that** operating in the sleep mode comprises operating the seismic base station 104 in a low power mode.

11. The sensor system of claim 9, **characterized in that** operating in the sleep mode comprises shutting off power to the seismic sensor nodes 106.

12. The sensor system of claim 1, **characterized in that** the recorded seismic data is harvested by the Remotely Operated Vehicle (ROV).

13. A method for deployment of seismic sensor nodes 106 on the seafloor and collecting the seismic sensor nodes 106 used in a marine seismic survey, comprising:

deploying a sensor system 100 in water column comprising a hub 102; a seismic base station 104 on the hub 102; and a plurality of seismic sensor nodes 106 that are mounted outside of the seismic base station 104,

characterized in that the sensor system 102 will ascend through the water towards the seafloor by a Remotely Operated Vehicle (ROV),

characterized in that detaching the seismic sensor nodes 106 from the seismic base station 104 by the ROV's manipulator arm and positioned at recording positions on the seafloor,

characterized in that recoding the seismic data into seismic sensor nodes 106, and

characterized in that transmitting the recorded seismic data back to the seismic base station 104.

14. The method of claim 13, **characterized in that** further transmitting the recorded seismic data back to the seismic base station 104 by using an acoustic transponder.

15. The method of claim 13, **characterized in that** positioning the seismic sensor nodes 106 on the seafloor by an integrated navigation transponder configured on the seismic base station 104.

16. The method of claim 13, **characterized in that** activating the seismic base station 104 before each survey and starts recording the seismic data on the seafloor.

17. The method of claim 13, **characterized in that further** operating the seismic base station 104 in sleep mode between each survey to save power.

18. The method of claim 17, **characterized in that** operating in the sleep mode comprises operating the seismic base station 104 in a low power mode.

19. The method of claim 17, **characterized in that** operating in the sleep mode comprises shutting off power to the seismic sensor nodes 106.

20. The method of claim 13, **characterized in that** further harvesting the recorded seismic by the Remotely Operated Vehicle ROV.

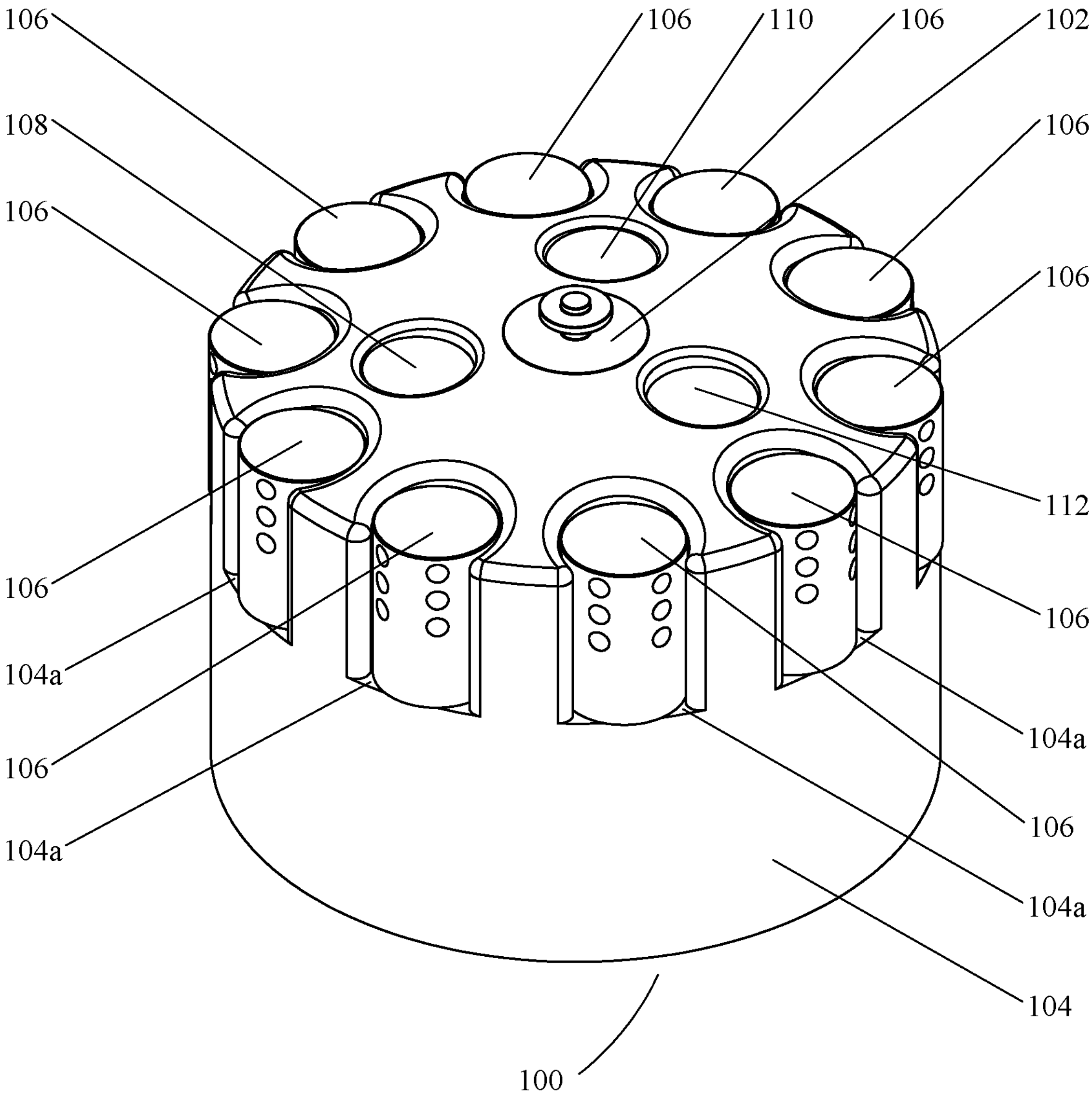

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FIG.1

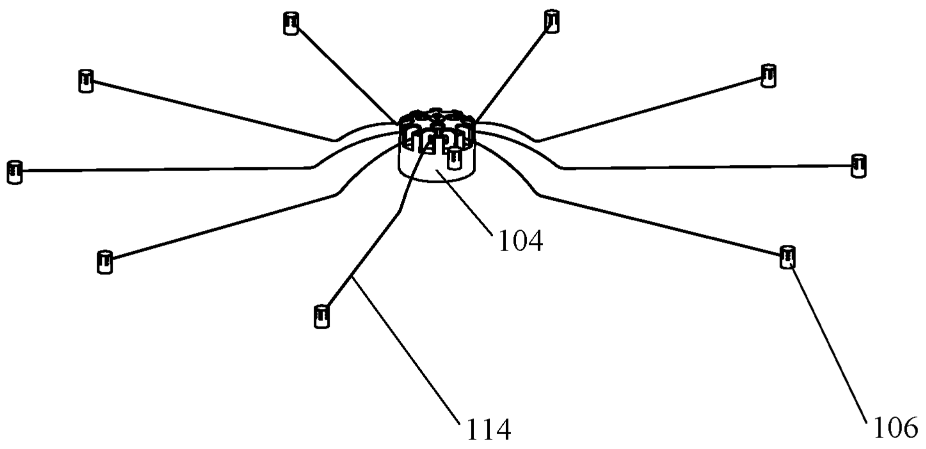

FIG.2

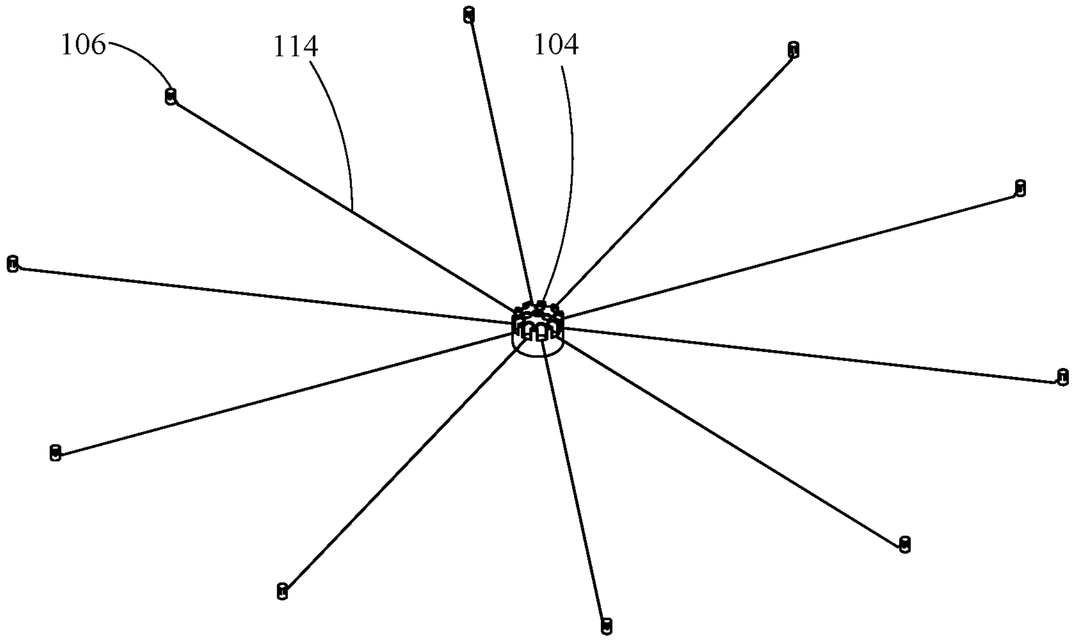

FIG.3

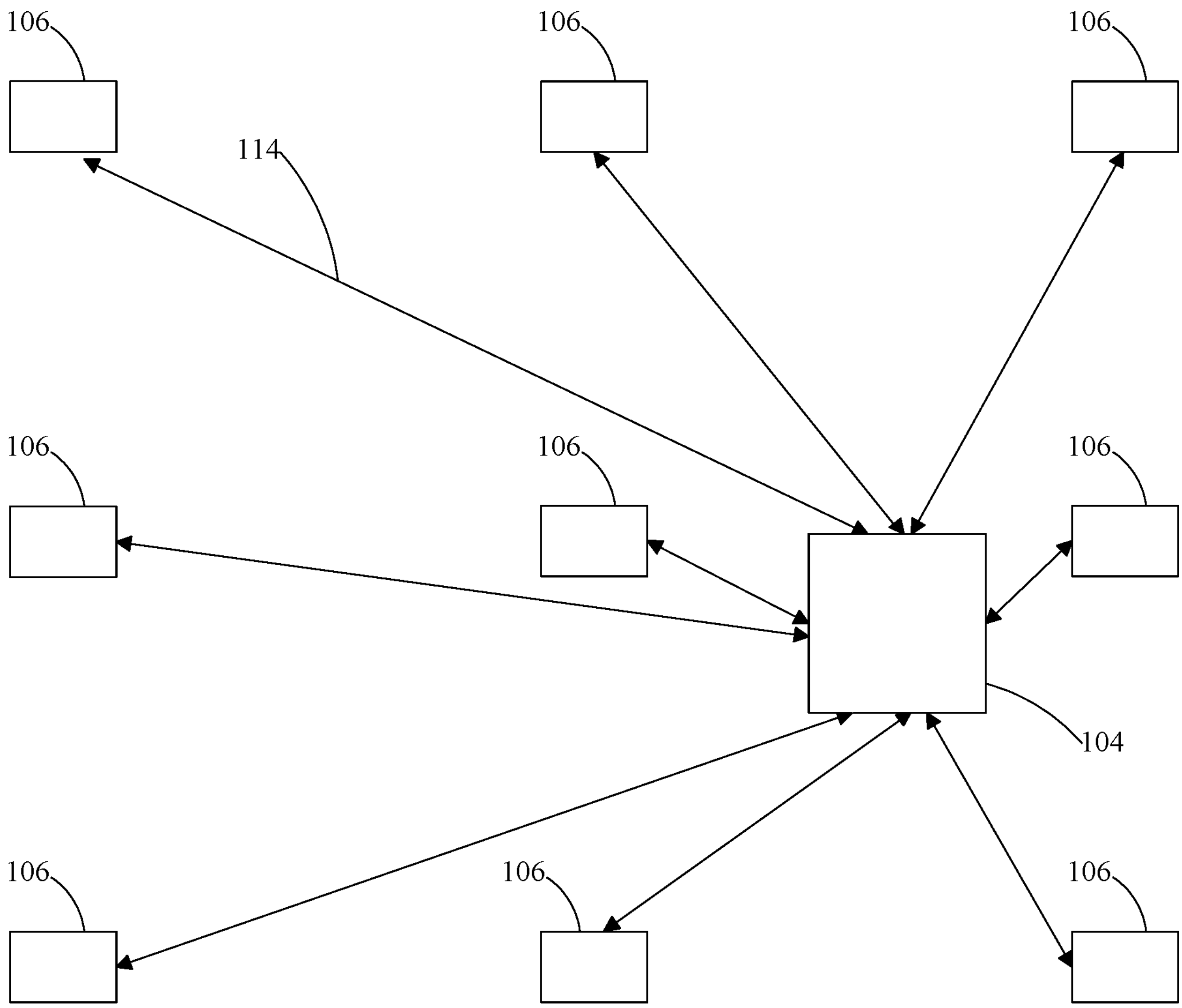

FIG.4

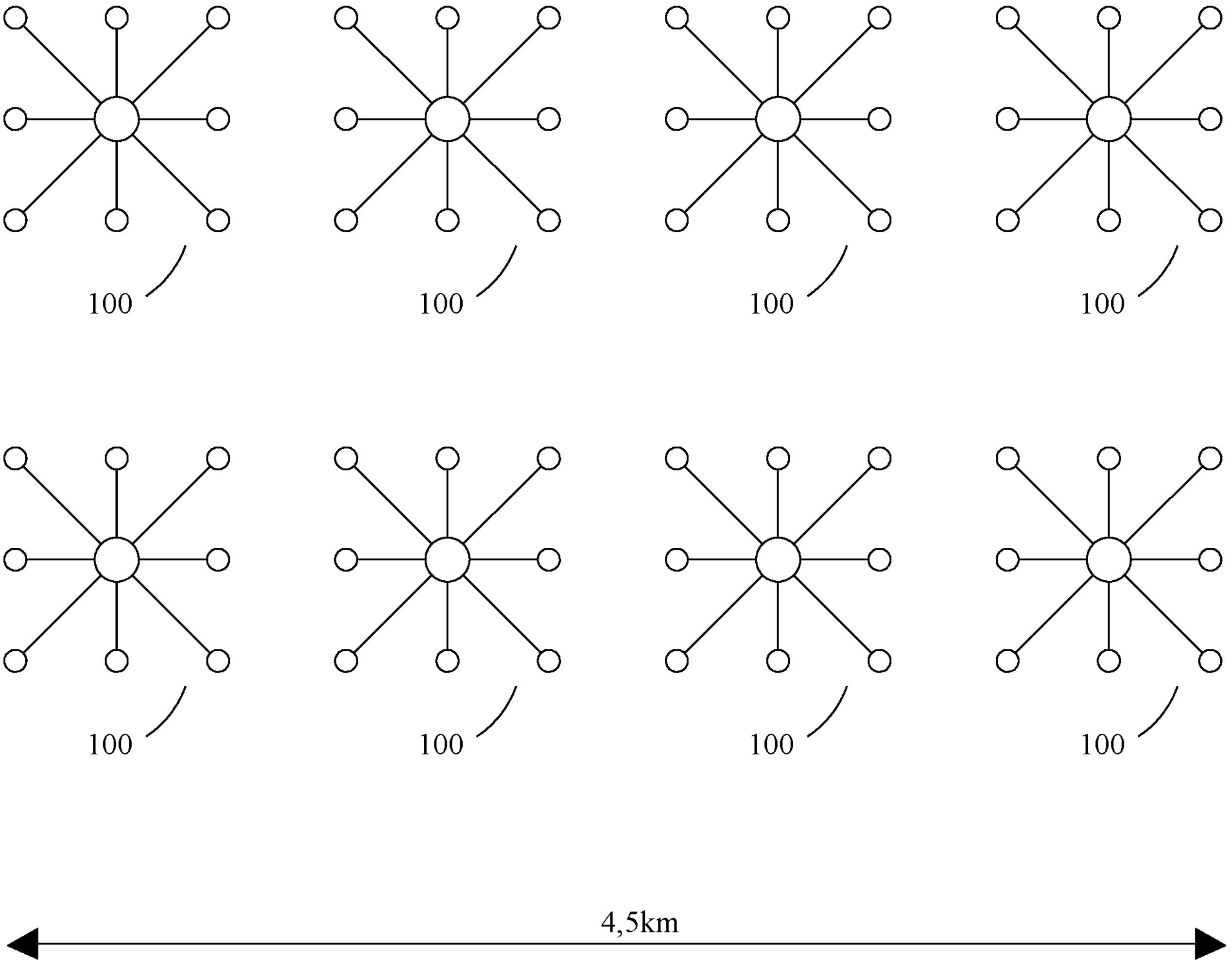

FIG.5