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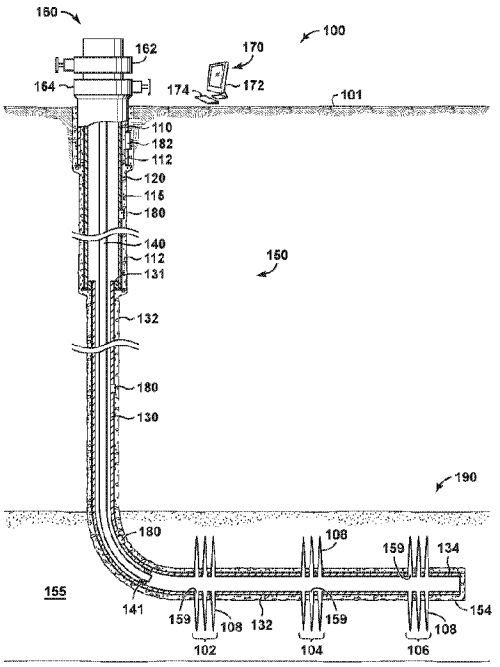
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(54) Title: METHODS AND SYSTEMS FOR OPERATING AND MAINTAINING A DOWNHOLE WIRELESS NETWORK



(57) Abrégé/Abstract:
Disclosed herein are methods and systems for operating and maintaining downhole wireless networks. The methods and systems use a downhole tool, such as a hydrophone, as part of the downhole wireless network. The downhole tool may be used, for example, to perform maintenance on the downhole wireless network, to overcome and/or correct communications errors along the network, to update and reprogram communication nodes in the downhole wireless network, to determine characteristics of nearby geologic formations, reservoirs, fluids, and tubulars, and/or to act as a substitute or topside node for the downhole wireless network.

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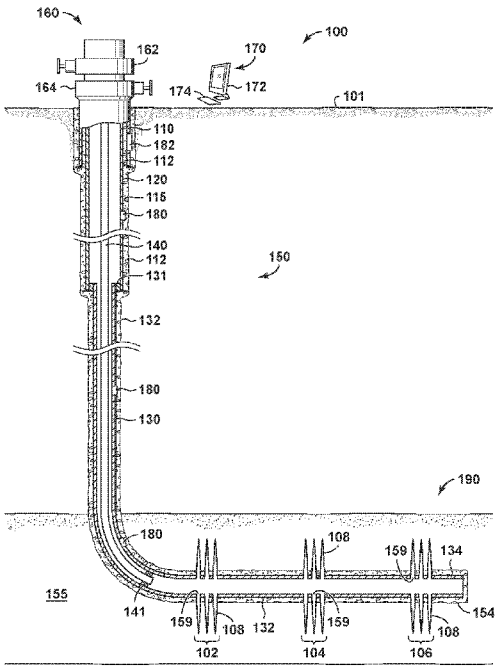


FIG. 1

(57) Abstract: Disclosed herein are methods and systems for operating and maintaining downhole wireless networks. The methods and systems use a downhole tool, such as a hydrophone, as part of the downhole wireless network. The downhole tool may be used, for example, to perform maintenance on the downhole wireless network, to overcome and/or correct communications errors along the network, to update and reprogram communication nodes in the downhole wireless network, to determine characteristics of nearby geologic formations, reservoirs, fluids, and tubulars, and/or to act as a substitute or topside node for the downhole wireless network.

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METHODS AND SYSTEMS FOR OPERATING AND MAINTAINING A DOWNHOLE WIRELESS NETWORK

[0001] <This paragraph is intentionally left blank.>

FIELD OF THE INVENTION

[0002] The present disclosure relates to methods and systems for operating and maintaining downhole wireless networks. In particular, the present disclosure relates to methods and systems that use a downhole tool to replace, repair, maintain, and/or optimize communication nodes in a downhole wireless network, and to enable efficient communication between the surface and downhole communication nodes. Additionally, the present disclosure relates to methods and systems that use a downhole tool for sensing and controlling operations relating to downhole devices.

BACKGROUND

[0003] In the oil and gas industry, various communications systems have been introduced for monitoring downhole conditions and hydrocarbon production operations. For example, various wired and wireless technologies have been proposed to collect data from the downhole environment and transmit it to the operator at the surface.

[0004] As an example, wireless telemetry systems, such as downhole wireless networks, have been proposed. The wireless telemetry system may include a network of various communication nodes that exchange information with each other to manage data communication within the wellbore. Some wireless telemetry systems operate using radio transmissions. However, the use of radio transmissions may be impractical or unavailable in certain wellbore environments or during certain operations within the wellbore. Other wireless telemetry systems may use an acoustic wireless network that transmit acoustic signals, such as vibrations, via a tone transmission medium. In either systems, there are typically a plurality of communication nodes spaced apart along the length of a tubular member within the wellbore.

[0005] Throughout the lifetime of the operation of the wireless telemetry system, there can be difficulties with the reliability and accuracy of the network. For example, the network can become severed if one or more communication nodes becomes unresponsive or fails to properly transmit signals to the next node. As another example, the network may become less reliable due to the continually changing and unpredictable conditions within the wellbore. That is, the acoustic conditions within the wellbore may be affected by formation variations, cementation

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variations, varying fluid compositions within the wellbore, fracking operations, and/or hydrocarbon production operations. The changes in the acoustic conditions may affect the ability of the nodes to properly communicate with one another via acoustic transmissions. Additionally, power failures, mechanical failures, and/or programming software failures impacting one or more of the nodes may impact the efficacy of the network.

[0006] Thus, there is a need for methods and systems to aid in the diagnosis of errors in the downhole wireless network, and/or for methods and systems to aid in the reliable operation and maintenance of the downhole wireless network. Further, there is a need for methods and systems for repairing or healing a downhole wireless network that has begun to operate unreliably or has become severed.

[0007] Background references may include (i) U.S. Patent Nos. 5,924,499; 6,462,672; 6,899,178; 6,909,667; 6,912,177; 7,228,902; 7,249,636; 7,477,160; 8,115,651; 9,557,434; 9,631,485; 9,759,062; 9,816,373; 9,863,222; 9,879,525; 10,100,635; and 10,132,149 (ii) U.S. Patent Application Publication Nos. 2008/0030365; 2015/0292319; 2015/0300159; 2015/0354351; 2016/0076363; and 2016/0215612; 2018/0058191; 2018/0058198; 2018/0058202; 2018/0058203; 2018/0058204; 2018/0058205; 2018/0058206; 2018/0058207; 2018/0058208; 2018/0058209; 2018/0066510; and (iii) U.S. Patent Application Serial No. 15/666334.

SUMMARY

[0008] A method of operating a downhole wireless network is disclosed. The downhole wireless network includes a plurality of communication nodes spaced along a wellbore and attached to one or more tubulars within the wellbore. Each of the communication nodes is configured to transmit data packets at acoustic frequencies from node to node along the wellbore. A downhole tool comprising a communications device is lowered into the wellbore. The downhole tool is used as part of the downhole wireless network.

[0009] According to another aspect, a downhole wireless network is disclosed. The downhole wireless network includes a plurality of communication nodes spaced along a wellbore and attached to one or more tubulars within the wellbore. Each of the communication nodes is configured to transmit data packets at acoustic frequencies from node to node along the wellbore. A downhole tool, comprising a communications device, is lowered into the wellbore. The downhole tool is used as part of the downhole wireless network.

DESCRIPTION OF THE FIGURES

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[0010] Figure 1 is a side, cross-sectional view of an illustrative wellbore having been completed as a cased hole completion. A series of communication nodes are placed along a casing string as part of a downhole telemetry system in the wellbore.

[0011] Figure 2A is a schematic of an exemplary communication node. Figure 2B is a cross-sectional view of an exemplary communication node taken along the longitudinal axis of the node.

[0012] Figure 3A is an illustration of a severed downhole wireless network, and Figure 3B is an illustration of using a hydrophone to reconnect the severed downhole wireless network.

[0013] Figure 4 is an illustrative ultrasonic hydrophone that may be used in the methods and systems described herein.

[0014] Figure 5 is a flowchart of an illustrative embodiment of the methods described herein.

DETAILED DESCRIPTION OF THE DISCLOSURE

[0015] Various specific embodiments, versions, and examples of the invention will now be described, including preferred embodiments and definitions that are adopted herein for purposes of understanding the claimed invention. While the following detailed description gives specific preferred embodiments, those skilled in the art will appreciate that these embodiments are exemplary only, and that the invention can be practiced in other ways. For purposes of determining infringement, the scope of the invention will refer to any one or more of the appended claims, including their equivalents, and elements or limitations that are equivalent to those that are recited. Any reference to the "invention" may refer to one or more, but not necessarily all, of the inventions defined by the claims.

Terminology

[0016] Various terms as used herein are defined below. To the extent a term used in a claim is not defined below, it should be given the broadest possible definition persons in the pertinent art have given that term as reflected in at least one printed publication or issued patent.

[0017] The articles "the", "a", and "an" are not necessarily limited to mean only one, but rather are inclusive and open ended to include, optionally, multiple such elements.

[0018] The directional terms, such as "above", "below", "upper", "lower", etc., are used for convenience in referring to the accompanying drawings. In general, "above", "upper", "upward" and similar terms refer to a direction toward the earth's surface along a wellbore, and

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"below", "lower", "downward" and similar terms refer to a direction away from the earth's surface along the wellbore. Continuing with the example of relative directions in a wellbore, "upper" and "lower" may also refer to relative positions along the longitudinal dimension of a wellbore rather than relative to the surface, such as in describing both vertical and horizontal wells.

[0019] As used herein, the term "and/or" placed between a first entity and a second entity means one of (1) the first entity, (2) the second entity, and (3) the first entity and the second entity. Multiple elements listed with "and/or" should be construed in the same fashion, i.e., "one or more" of the elements so conjoined. Other elements may optionally be present other than the elements specifically identified by the "and/or" clause, whether related or unrelated to those elements specifically identified. Thus, as a non-limiting example, a reference to "A and/or B", when used in conjunction with open-ended language such as "comprising" can refer, in one embodiment, to A only (optionally including elements other than B); in another embodiment, to B only (optionally including elements other than A); in yet another embodiment, to both A and B (optionally including other elements). As used herein in the specification and in the claims, "or" should be understood to have the same meaning as "and/or" as defined above. For example, when separating items in a list, "or" or "and/or" shall be interpreted as being inclusive, i.e., the inclusion of at least one, but also including more than one, of a number or list of elements, and, optionally, additional unlisted items. Only terms clearly indicated to the contrary, such as "only one of" or "exactly one of," or, when used in the claims, "consisting of," will refer to the inclusion of exactly one element of a number or list of elements. In general, the term "or" as used herein shall only be interpreted as indicating exclusive alternatives (i.e., "one or the other but not both") when preceded by terms of exclusivity, such as "either," "one of," "only one of," or "exactly one of".

[0020] As used herein, "about" refers to a degree of deviation based on experimental error typical for the particular property identified. The latitude provided the term "about" will depend on the specific context and particular property and can be readily discerned by those skilled in the art. The term "about" is not intended to either expand or limit the degree of equivalents which may otherwise be afforded a particular value. Further, unless otherwise stated, the term "about" shall expressly include "exactly," consistent with the discussion below regarding ranges and numerical data.

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[0021] As used herein, "any" means one, some, or all indiscriminately of whatever quantity.

[0022] As used herein, "at least one," in reference to a list of one or more elements, should be understood to mean at least one element selected from any one or more of the elements in the list of elements, but not necessarily including at least one of each and every element specifically listed within the list of elements and not excluding any combinations of elements in the list of elements. This definition also allows that elements may optionally be present other than the elements specifically identified within the list of elements to which the phrase "at least one" refers, whether related or unrelated to those elements specifically identified. Thus, as a non-limiting example, "at least one of A and B" (or, equivalently, "at least one of A or B," or, equivalently "at least one of A and/or B") can refer, in one embodiment, to at least one, optionally including more than one, A, with no B present (and optionally including elements other than B); in another embodiment, to at least one, optionally including more than one, B, with no A present (and optionally including elements other than A); in yet another embodiment, to at least one, optionally including more than one, A, and at least one, optionally including more than one, B (and optionally including other elements). The phrases "at least one", "one or more", and "and/or" are open-ended expressions that are both conjunctive and disjunctive in operation. For example, each of the expressions "at least one of A, B and C", "at least one of A, B, or C", "one or more of A, B, and C", "one or more of A, B, or C" and "A, B, and/or C" means A alone, B alone, C alone, A and B together, A and C together, B and C together, or A, B and C together.

[0023] As used herein, "based on" does not mean "based only on", unless expressly specified otherwise. In other words, the phrase "based on" describes both "based only on," "based at least on," and "based at least in part on."

[0024] As used herein, “couple” refers to an interaction between elements and is not meant to limit the interaction to direct interaction between the elements and may also include indirect interaction between the elements described. Couple may include other terms, such as "connect", "engage", "attach", or any other suitable terms.

[0025] As used herein, "one embodiment," "an embodiment," "some embodiments," "one aspect," "an aspect," "some aspects," "some implementations," "one implementation," "an implementation," or similar construction means that a particular component, feature, structure, method, or characteristic described in connection with the embodiment, aspect, or

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implementation is included in at least one embodiment and/or implementation of the claimed subject matter. Thus, the appearance of the phrases "in one embodiment" or "in an embodiment" or "in some embodiments" (or "aspects" or "implementations") in various places throughout the specification are not necessarily all referring to the same embodiment and/or implementation. Furthermore, the particular features, structures, methods, or characteristics may be combined in any suitable manner in one or more embodiments or implementations.

[0026] As used herein, "exemplary" is used exclusively herein to mean "serving as an example, instance, or illustration." Any embodiment described herein as "exemplary" is not necessarily to be construed as preferred or advantageous over other embodiments.

[0027] As used herein, "casing" refers to relatively large diameter pipe (relative to the diameter of the drill pipe of the drill string used to drill a particular wellbore) that is assembled by coupling casing sections in an end-to-end configuration that is positioned within a previously-drilled wellbore and that remains within the wellbore after completion of the wellbore to seal walls of the subterranean formations within the wellbore. Furthermore, the term casing includes wellbore casing and casing sections as well as wellbore liner and liner sections.

[0028] As used herein, "cement" refers to an initially flowable material which subsequently hardens to thereby seal and secure a tubular string in a well, or to form a seal or plug in a well. A cement may be composed substantially of cementitious material and/or it may include various other types of materials (such as epoxies, other polymers, elastomers, resinous materials, inert fillers, swellable materials, etc.). Cement may be used to seal an annulus between two tubular strings and/or cement may be used to seal an annulus between a tubular string and a formation surface, or to fill the casing or borehole.

[0029] As used herein, the term "communication node" may be used to refer to a topside communication node, an intermediate communication node, and/or a sensor communication node.

[0030] As used herein, the term "conduit" refers to a tubular member forming a physical channel through which something is conveyed. The conduit may include one or more of a pipe, a manifold, a tube or the like, or the liquid contained in the tubular member.

[0031] As used herein, the term "determining" encompasses a wide variety of actions and may include calculating, computing, processing, deriving, investigating, looking up (e.g., looking up in a table, database, or other data structure), ascertaining, and the like. Determining

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may also refer to resolving, selecting, choosing, establishing, and the like.

[0032] As used herein, the term "fluid" refers to gases, liquids, and combinations of gases and liquids, as well as to combinations of gases and solids where the gas is the majority component of the fluid, and combinations of liquids and solids where the liquid is the majority component of the fluid.

[0033] As used herein, the term "fluid flow measurement" refers to measuring one or more fluid flow parameters including, but not limited to, one or more of velocity, volume, pressure, resistivity, vibration, pressure drop, temperature, impedance, attenuation, density, viscosity, flow type, and the like. Such measurements can be used to determine, for example, fluid viscosity, fluid composition, phase fraction, annular distribution of flows and phases across a cross-section, flow-rate, and the like.

[0034] As used herein, the term "flow" refers to a current or stream of a fluid. Flow can be understood as the quantity of a fluid that passes a point per unit of time. Factors that affect flow can include, but are not limited to, pressure (e.g., flow is directly proportional to the pressure difference across a tube), length (e.g., flow is inversely proportional to the length of a tube), viscosity (e.g., flow is inversely proportional to the viscosity of the fluid), temperature of the fluid, fluid density, compressibility of the fluid, number of phases of the fluid (i.e., single phase or multiphase), friction, and chemical properties of the fluid.

[0035] As used herein, the term "formation" refers to any definable subsurface region. The formation may contain one or more hydrocarbon-bearing layers, one or more non-hydrocarbon containing layers, an overburden, and/or an underburden of any geologic formation.

[0036] As used herein, the term "hydrocarbon" refers to an organic compound that includes primarily, if not exclusively, the elements hydrogen and carbon. Hydrocarbons generally fall into two classes: aliphatic hydrocarbons, also known as straight chain hydrocarbons, and cyclic hydrocarbons, also known as closed ring hydrocarbons. While hydrocarbons generally comprise the elements hydrogen and carbon, in some embodiments hydrocarbons may also comprise minor amounts of other elements or compounds, such as, but not limited to, halogens, metallic elements, nitrogen, oxygen, sulfur. Examples of hydrocarbon-containing materials include any form of natural gas, oil, coal, and bitumen.

[0037] As used herein, the term "condensable hydrocarbons" refers to those hydrocarbons that condense at about 15 °C and one atmosphere of pressure. Condensable hydrocarbons may include, for example, a mixture of hydrocarbons having carbon numbers greater than 3.

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[0038] As used herein, the term "hydrocarbon fluids" refers to a hydrocarbon or mixtures of hydrocarbons that are gases or liquids. For example, hydrocarbon fluids may include a hydrocarbon or mixtures of hydrocarbons that are gases or liquids at formation conditions, at processing conditions, or at ambient conditions (i.e., at about 20 °C and 1 atm pressure). Hydrocarbon fluids may include, for example, oil, natural gas, gas condensates, coal bed methane, shale oil, pyrolysis oil, and other hydrocarbons that are in a gaseous or liquid state.

[0039] As used herein, "hydrocarbon exploration" refers to any activity associated with determining the location of hydrocarbons in subsurface regions. Hydrocarbon exploration normally refers to any activity conducted to obtain measurements through acquisition of measured data associated with the subsurface formation and the associated modeling of the data to identify potential locations of hydrocarbon accumulations. Accordingly, hydrocarbon exploration may include acquiring measurement data, modeling of the measurement data to form subsurface models, and determining the likely locations for hydrocarbon reservoirs within the subsurface. The measurement data may include seismic data, gravity data, electromagnetic data, geochemical data, and the like. In some embodiments, hydrocarbon exploration activities may also include drilling exploratory wells, obtaining core samples or other fluid samples, and acquiring measurement data from the core or fluid samples.

[0040] As used herein, "hydrocarbon development" refers to any activity associated with the planning of extraction and/or access to hydrocarbons in subsurface regions. Hydrocarbon development normally refers to any activity conducted to plan for access to and/or for production of hydrocarbons from the subsurface formation and the associated modeling of the data to identify preferred development approaches and methods. For example, hydrocarbon development may include modeling of the subsurface formation and extraction planning for periods of production, determining and planning equipment to be used and techniques to be used in extracting the hydrocarbons from the subsurface formation, and the like.

[0041] As used herein, "hydrocarbon production" refers to any activity associated with extracting hydrocarbons from subsurface locations, such as a well or other opening. Hydrocarbon production activities may refer to any activity conducted to form the wellbore along with any activity in or on the well after the well is completed. Accordingly, hydrocarbon production activities includes not only primary hydrocarbon extraction, but also secondary or tertiary production techniques, such as injection of gas or liquid for increasing drive pressure, mobilizing the hydrocarbons or treating the hydrocarbons by, for example, chemicals, hydraulic fracturing the wellbore to promote increased flow, well servicing, well logging, and

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other well and wellbore treatments.

[0042] As used herein, "hydrophone" includes any type of instrument for detecting and/or transmitting acoustic waves.

[0043] As used herein, "monitored section" and "monitored sections" refer to locations along the tubular members that include sensors and/or regions of interest.

[0044] As used herein, "unmonitored section" and "unmonitored sections" refer to locations along the tubular members that do not include sensors and/or are not regions of interest.

[0045] As used herein, "multilateral well system" refers to a well system having a primary or mother wellbore which extends from a wellhead down into a surface earth formation and at least one branch wellbore which intersects the primary or mother wellbore at a subsurface location. A lateral borehole may also extend from another lateral borehole.

[0046] As used herein, the term "multi-zone fluid producing well" or "multi-zone production well" refers to a hydrocarbon-producing well that includes at least two production zones.

[0047] As used herein, the terms "near real-time" and "real-time" are used interchangeably and refer to the systems and methods where the time delay introduced, by automated data processing or network transmission, between the occurrence of an event and the use of the processed data, such as for display or feedback and control purposes. For example, a near-real-time or real-time display depicts an event or situation as it existed at the current time minus the processing time, as nearly the time of the live event. The time delay with regard to "near real-time" or "real-time" can be on the order of several milliseconds to several minutes, several milliseconds to several seconds, or several seconds to several minutes.

[0048] As used herein, the terms "optimal", "optimizing", "optimize", "optimality", "optimization", as well as derivatives and other forms of those terms and linguistically related words and phrases, as used herein, are not intended to be limiting in the sense of requiring the present invention to find the best solution or to make the best decision. Although a mathematically optimal solution may in fact arrive at the best of all mathematically available possibilities, real-work embodiments of optimization routines, methods, models, and processes may work towards such a goal without ever actually achieving perfection. Accordingly, one of ordinary skill in the art having benefit of the present disclosure will appreciate that these terms, in the context of the scope of the present invention, are more general. The terms may

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describe one or more of: 1) working towards a solution which may be the best available solution, a preferred solution, or a solution that offers a specific benefit within a range of constraints; 2) continually improving; 3) refining; 4) searching for a high point or a maximum for an objective; 5) processing to reduce a penalty function; 6) seeking to maximize one or more factors in light of competing and/or cooperative interests in maximizing, minimizing, or otherwise controlling one or more other factors, etc.

[0049] As used herein, the term "potted" or "potting" refers to the encapsulation of electrical components and/or transducers with epoxy, elastomeric, silicone, or asphaltic or similar compounds for the purpose of excluding moisture or vapors. Potted components may or may not be hermetically sealed.

[0050] As used herein, the term "produced fluids" and "production fluids" refer to liquids and/or gases removed from a subsurface formation. Produced fluids may include both hydrocarbon fluids and non-hydrocarbon fluids. For example, produced fluids may include natural gas, pyrolyzed shale oil, synthesis gas, a pyrolysis product of coal, carbon dioxide, hydrogen sulfide, and water (including steam).

[0051] As used herein, the term "production casing" includes a liner string or any other tubular body fixed in a wellbore along a zone of interest.

[0052] As used herein, the term "production optimization" refers to any method, device, control device, valve, chemical, metrics, data analysis, and/or system, that can be used to improve hydrocarbon fluid production efficiency, hydrocarbon fluid production rates, hydrocarbon fluid recovery, produced gas/oil ratio, hydrocarbon fluid phase, utilization of the production plant to achieve higher throughput, water-cut, workovers, etc. Production optimization can be real-time production optimization including partial or complete automation, and/or optimization of control settings. Production optimization can be accomplished, for example, but not limited to, chemically by preventing or inhibiting scale, paraffin, asphaltene, and/or corrosion using inhibitors of one or more thereof; extending field life using for example, defoamers, emulsifiers, foamers, flow improvers, tracer dyes, and/or water clarifiers, acidizing, etc.; reinstating or improving flow performance chemically using, for example, dissolvers, cleaners, scavengers, adsorbents, water flooding, CO_2 flooding, etc.; mechanically, for example, but not limited to artificial lift, using, for example, pumps, including but not limited to, electric submersible pumps, gas lift, horizontal surface pumps, subsea lift systems, dewatering pump systems, geothermal pump systems, industrial pump systems, etc.; gas/water injection optimization; tubing size optimization; perforation

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optimization; nitrogen circulation; and the like. In certain cases, production optimization may include sealing a lost circulation zone.

[0053] Production optimization can include, but is not limited to, one or more of the following: equalizing reservoir inflow along a length of the wellbore, partially choking flow, delaying water or gas breakthrough by reducing annular velocity across a selected interval, e.g., such as the heel of a horizontal well, adjusting flow from individual zones of a production well including one or more zones of a multi-zone production well, e.g., that are over- or under-pressured, slowing water, and/or gas encroachment, and reducing the amount of bypassed reserves by equalizing a pressure drop along a length of a wellbore, e.g., so as to promote uniform flow of oil and gas through a formation so that the arrivals of water and gas are delayed and simultaneous. Production optimization can be accomplished using, for example, but not limited to, one or more of control devices including for example, inflow control devices (ICDs) that can be used to manage fluid outflow in injection wells. ICDs can be placed both in injection and producer wells; or more remotely actuated downhole valves to shut off or reduce fluid flow from one or more well production zones; outflow control devices, valves, and corresponding actuation devices, wellbore isolation devices including for example, tool seals, packers, cement plugs, bridge plugs, chemical control devices, and the like.

[0054] "Range": Numerical data, such as concentrations, dimensions, amounts, and the like, may be presented herein in a range format. It is to be understood that such range format is used merely for convenience and brevity and should be interpreted flexibly to include not only the numerical values explicitly recited as the limits of the range, but also to include all the individual numerical values or sub-ranges encompassed within that range as if each numerical value and sub-range is explicitly recited. For example, a range of about 1 to about 200 should be interpreted to include not only the explicitly recited limits of 1 and about 200, but also to include individual sizes such as 2, 3, 4, etc. and sub-ranges such as 10 to 50, 20 to 100, etc. Similarly, it should be understood that when numerical ranges are provided, such ranges are to be construed as providing literal support for claim limitations that only recite the lower value of the range as well as claims limitation that only recite the upper value of the range. For example, a disclosed numerical range of 10 to 100 provides literal support for a claim reciting "greater than 10" (with no upper bounds) and a claim reciting "less than 100" (with no lower bounds).

[0055] As used herein, the term "sealing material" refers to any material that can seal a cover of a housing to a body of a housing sufficient to withstand one or more downhole

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conditions including but not limited to, for example, temperature, humidity, soil composition, corrosive elements, pH, and pressure.

[0056] As used herein, the term "sensor" includes any sensing device or gauge, such as an electrical device or gauge. The sensor may be capable of monitoring and/or detecting and/or measuring a fluid flow parameter, including for example, but not limited to pressure, pressure drop, temperature, fluid flow, fluid type, volumetric flow, fluid velocity, vibration, resistivity, impedance, attenuation, or other fluid flow data. Alternatively, the sensor may be a position or location sensor.

[0057] As used herein, the term "subsurface" refers to the region occurring below the Earth's surface. For example, the subsurface may be beneath the top surface of any mass of land at any elevation or over a range of elevations, whether above, below, or at sea level, and/or beneath the floor surface of any mass of water, whether above, below, or at sea level.

[0058] As used herein, and unless connotations suggest otherwise, the term "surface" refers to the top surface of any mass of land at any elevation of over a range of elevations, whether above, below, or at sea level, and/or beneath the floor surface of any mass of water, whether above, below, or at sea level.

[0059] As used herein, the term "topside communication node" as used herein, refers to a communication node that can be located topside, proximate a surface. The topside communication node can be a virtual topside communication node that can be located subsurface or downhole, and can function as a topside node. The virtual topside communication node can be located, for example, at locations including but not limited to, the bottom of a vertical section, e.g., at the start of a deviated section, for example, in order to communicate with multi-zone horizontal sections of a multi-zone well. Data can be brought to the surface, e.g., to a receiver located at the surface, using, for example, but not limited to, one or more of a wireless connection, e.g., an RF wireless connection, a cable, a fiber optic cable, and the like.

[0060] As used herein, the terms "tubular member" or "tubular body" or "subsurface pipe" refer to any pipe, such as a joint or casing, a portion of a liner, a drill string, a production tubing, an injection tubing, a pup joint, a buried pipeline, underwater piping, or above-ground piping.

[0061] As used herein, the term "wellbore" refers to a hole in the subsurface made by drilling or insertion of a conduit into the subsurface. A wellbore may have a substantially circular cross section or other cross-sectional shape. As used herein, the term "well", when

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referring to an opening in the formation, may be used interchangeably with the term "wellbore".

[0062] As used herein, the term "well data" may include seismic data, electromagnetic data, resistivity data, gravity data, well log data, core sample data, and combinations thereof. The well data may be obtained from memory or from the equipment in, around, or associated with the wellbore. The well data may also include the data associated with the equipment installed within or near the wellbore and the configuration of the wellbore equipment. For example, the well data may include the composition of the tubular members, thickness of the tubular members, length of the tubular members, composition and/or other fluid properties within, near, or around the wellbore, formation properties, and/or other suitable properties associated with the wellbore.

[0063] As used herein, the terms "zone" or "zone of interest" refer to a portion of a formation containing hydrocarbons. Zones of interest may also include formations containing brines or useable water which are to be isolated.

Description

[0064] Robust acoustic telemetry sensing and telemetry may use a combination of communication and sensing paths, including communication from topsides (e.g., at a wellhead) to one or more metallic tubulars or pipes below grade, using the tubulars as a waveguide. Depending on the application and downhole conditions, it may be also advantageous to communicate from within a tubular containing fluid or mixed phases, to acoustic telemetry nodes one or more casings away from the fluid. Aspects disclosed herein use ultrasonic acoustic telemetry to perform two-way communication from a wireline device to nodes on tubulars. Further, this communication from within a tubular to devices outside of the housing may be used to characterize the intervening media of metallic tubulars, cement, mud, sand and other media. Use of an ultrasonic communication device within fluid also enables bridging or completing an acoustic network above, below, or above and below a current location.

[0065] According to disclosed aspects, the wireline device may include a high speed, long range ultrasonic hydrophone. The hydrophone may operate within a frequency range of between about 50 kHz and about 1 MHz. The hydrophone may be beneficially used for two-way communication via ultrasonic telemetry with one or more downhole communication nodes either inside or outside a tubular member, such as a production tubular or a casing tubular. The communication may comprise two-way communication between a communication node and the hydrophone, or with the hydrophone initiating and/or controlling telemetry with

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communication nodes.

[0066] The present invention is related to the use of downhole telemetry systems, such as downhole wireless networks, and in particular, to methods and systems for operating and maintaining such networks. The downhole wireless network employs a series of communication nodes spaced along a tubular member in a wellbore. The communication nodes operate to wirelessly transmit packets of data (e.g., sensor values, diagnostic information, log entries, or other information about one or more conditions within the wellbore), in a node-to-node manner as further described herein, and to deliver the information from the subsurface to the topside. Over the operational life of the network, there may be instances where the network does not operate properly. For example, there may be a communications failure between two or more nodes. As another example, over time the acoustic environment in the wellbore may change. Furthermore, nodes may need to be reprogrammed or updated to be more accurate and reliable. The present methods and techniques provide means for performing maintenance on the downhole wireless network, for overcoming and/or correcting communications errors along the network, and for updating, reprograming, and/or recharging nodes in the network.

[0067] In one embodiment, a downhole tool including a hydrophone may be used to obtain data from a portion of the network where communication has been lost or severed. For example, the methods may comprise detecting a communications error in the downhole wireless network; identifying one or more communication nodes that are no longer transmitting data; lowering the downhole tool through the wellbore to the location of the communication nodes that are no longer transmitting data; and collecting data from the communication node below the communication node that is no longer transmitting; and using the downhole tool to transmit the data to the surface. In some embodiments, the methods and systems may further comprise using the downhole tool to diagnose the error with the malfunctioning communication node. If the error is due to a problem with the programming of the node, the downhole tool can transmit a new program to the malfunctioning communication node to correct the error.

[0068] The hydrophone may be used for other purposes, such as: loading new software onto communication nodes to change or otherwise improve the functionality thereof; optimizing communication settings even when the software itself is not updated, characterizing drilling or production fluids; and/or sensing and/or controlling downhole tools, such as sleeves, valves, flow controllers, which are equipped to communicate via ultrasound telemetry.

[0069] The present methods and techniques may be further understood with reference to

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the Figures, which are described further below. In certain figures (such as Figure 1), the top of the drawing page is intended to be toward the earth surface and the bottom of the drawing page toward the well bottom. While wells are commonly completed in a substantially vertical orientation, it is understood that wells may also be inclined and or horizontally completed (as shown in Figure 1). Thus, when the descriptive terms "up" and "down" or "upper" and "lower" or similar terms are used in reference to a drawing or in the claims, they are intended to indicate relative location on the drawing page or with respect to well descriptions, and are not necessarily an absolute orientation in the ground, as at least some embodiments of the present inventions have utility no matter how the wellbore is oriented. Thus, the present inventions may have equally utility in vertically completed wells, horizontally completed wells, or in multi-lateral deviated wells as further described herein.

[0070] The present methods and techniques described herein may also be better appreciated with reference to flow diagrams (such as those in Figure 5). While for purposes of simplicity of explanation, the illustrated methodologies may be shown and described as a series of blocks in Figure 5, it is to be appreciated that the methodologies are not limited by the order of the blocks, as some blocks can occur in different orders and/or concurrently with other blocks from that shown and described. Moreover, less than all the illustrated blocks may be required to implement various embodiments of an example methodology. Blocks may be combined or separated into multiple components. Furthermore, additional and/or alternative methodologies can employ additional blocks not shown herein. While the figures illustrate various actions occurring serially, it is to be appreciated that various actions could occur in series, substantially in parallel, and/or at substantially different points in time.

[0071] Figure 1 is a side, cross-sectional view of an illustrative well site **100**. The well site **100** includes a wellbore **150** that penetrates into a subsurface formation **155**. The wellbore **150** has been completed as a cased-hole completion for producing hydrocarbon fluids. The well site **100** also includes a well head **160**. The well head **160** is positioned at an earth surface **101** to control and direct the flow of formation fluids from the subsurface formation **155** to the surface **101**.

[0072] The well head **160** may be any arrangement of pipes or valves that receive reservoir fluids at the top of the well. In the arrangement of Figure 1, the well head **160** is a so-called Christmas tree. A Christmas tree is typically used when the subsurface formation **155** has enough *in situ* pressure to drive production fluids from the formation **155**, up the wellbore **150**, and to the surface **101**. The illustrative well head **160** includes a top valve **162** and a bottom

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valve **164**. In some contexts, these valves are referred to as "master valves". Other valves may also be used. In a subsea context, the wellhead may also include a lower marine riser package (not shown).

[0073] It is understood that rather than using a Christmas tree, the well head **160** may alternatively include a motor (or prime mover) at the surface **101** that drives a pump. The pump, in turn, reciprocates a set of sucker rods and a connected positive displacement pump (not shown) downhole. The pump may be, for example, a rocking beam unit or a hydraulic piston pumping unit. Alternatively still, the well head **160** may be configured to support a string of production tubing having a downhole electric submersible pump, a gas lift valve, or other means of artificial lift (not shown). The present invention is not limited by the configuration of production equipment at the surface unless expressly noted in the claims.

[0074] The wellbore **150** in Figure 1 has been completed with a series of pipe strings, referred to as casing. First, a string of surface casing **110** has been cemented into the formation. Cement is shown in an annular bore **115** of the wellbore **150** around the surface casing **110**. The cement is in the form of an annular sheath **112**. The surface casing **110** has an upper end in sealed connection with the lower valve **164**.

[0075] Next, at least one intermediate string of casing **120** is cemented into the wellbore **150**. The intermediate string of casing **120** is in sealed fluid communication with the upper master valve **162**. A cement sheath **112** is again shown in a bore **115** of the wellbore **150**. The combination of the casing **110/120** and the cement sheath **112** in the bore **115** strengthens the wellbore **150** and facilitates the isolation of formations behind the casing **110/120**.

[0076] It is understood that a wellbore **150** may, and typically will, include more than one string of intermediate casing **120**. In some instances, an intermediate string of casing may be a liner. Some of the intermediate strings of casing may be only partially cemented into place, depending on regulatory requirements and the presence of migratory fluids in any adjacent strata.

[0077] Finally, a production string **130** is provided. The production string **130** is hung from the intermediate casing string **120** using a liner hanger **131**. The production string **130** is a liner that is not tied back to the surface **101**. Preferably, all of the production liner **130** is cemented in place. In the arrangement of Figure 1, a cement sheath **132** is provided around the liner **130** along its entire length.

[0078] The production liner **130** has a lower end **134** that extends to an end **154** of the

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wellbore **150**. For this reason, the wellbore **150** is said to be completed as a cased-hole well. In Figure 1, the production liner **130** extends through a horizontal portion **190** of the formation **155**. The horizontal portion **190** of the wellbore **150** typically extends for many hundreds of feet. For example the horizontal portion **190** may extend for over 250 feet, or over 1,000 feet, or even more than 5,000 feet. Extending the horizontal portion **190** of the wellbore **150** such great distances significantly increases the exposure of the wellbore **150** to the formation **155**.

[0079] The formation **155** may be any hydrocarbon-bearing formation. However, in some embodiments, the formation may be a carbonate or sand formation having good consolidation but poor permeability, or may be a shale formation having low permeability. For example, in some embodiments, the formation may have a permeability of less than 100 milliDarcies ("mD"), or less than 50 mD, or less than 10 mD, or less than 1 mD. It is common for wells that are completed in so-called "tight" or "unconventional" formations to be completed horizontally as illustrated in Figure 1. Horizontal completions not only dramatically increase exposure of the producing rock face to the wellbore, but also enable the operator to create fractures that are substantially transverse to the direction of the wellbore. Those of ordinary skill in the art may understand that a rock matrix will generally "part" in a direction that is perpendicular to the direction of least principal stress. For deeper wells, that direction is typically substantially vertical. While Figure 1 illustrates a horizontally completed well, those skilled in the art would understand that the present methods and techniques would have equal utility in optimizing stimulation operations in other well arrangements, such as vertically completed wells or in multi-lateral deviated wells.

[0080] The wellbore **150** illustrated in Figure 1 has been perforated **159** for a fracturing operation. That is, as part of the well completion process, the casing has been perforated, whereby lateral holes have been shot through the casing and the cement sheath surrounding the casing to allow hydrocarbon fluids to flow into the wellbore. Various techniques may be used for creating the perforations. Common techniques use a wellbore tool that includes a perforating gun, and optionally, a fracturing plug. The wellbore tool may be a wireline tool or may be an autonomous tool (i.e., a tool that does not require a wireline and is not mechanically tethered to equipment external to the wellbore).

[0081] The wellbore **150** comprises sets of perforations **159** are provided in three separate zones **102**, **104**, and **106**. Each zone may be of any length, but generally each zone may represent, for example, a length of up to about 200 feet, or up to 100 feet, or up to 50 feet. In general, the length of each zone can depend on a number of factors, such as the type of rock

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material in the zone, the permeability of the zone, the porosity of the zone, and/or the hydrocarbon fluid composition in the zone. As described further below, the methods and techniques described herein may be used to determine the optimal length and spacing of desired fracturing zones. While only three sets of perforations **159** are shown, it is understood that the horizontal portion **190** may have many more sets of perforations **159** in additional zones.

[0082] The wellbore **150** of Figure 1 also has a string of injection tubing **140**. The injection tubing **140** extends from the well head **160** down to the subsurface formation **155**. In the arrangement of Figure 1, the injection tubing **140** terminates proximate an upper end of the subsurface formation **155**. In operation, the operator may stimulate and treat each zone **102**, **104**, and **106** separately and sequentially. Therefore, it is understood that the injection tubing **140** can be pulled through the horizontal portion of the wellbore **150** so that the injection fluids may be injected through the perforations **159** in zones **102**, **104**, and **106** separately and sequentially as desired.

[0083] A packer **141** is provided at a lower end of the injection tubing **140**. The packer **141** is set when an injection fluid, such as an acid and/or fracturing fluid, is being injected through a set of perforations **159**. The packer **141** will be released when it is time to move the injection tubing **140** to a different zone, or to remove it from the wellbore **150** completely.

[0084] In preparation for the production of hydrocarbons, the operator may wish to stimulate the formation **155** by conducting an acidization operation. This serves to clean out residual drilling mud along both the wall of the borehole **115** and into the near-wellbore region (the region within formation **155** close to the production casing **130**). An acidization operation can be done by injecting an acid solution down the wellbore and through the perforations. The use of an acidizing solution is particularly beneficial when the formation comprises carbonate rock. Thus, in some embodiments, the operator may inject a concentrated formic acid or other acidic composition into the wellbore, and direct the fluid into selected zones of interest. The acid helps to dissolve carbonate material, thereby opening up porous channels through which hydrocarbon fluids may flow into the wellbore. In addition, the acid helps to dissolve drilling mud that may have invaded the formation. The acidization may be conducted alone or in addition to a fracturing operation, such as before or after a fracturing operation.

[0085] In some embodiments, the operator may wish to fracture the formation **155**. This is done by injecting a fracturing fluid under high pressure through the perforations **159** and into the formation **155**. The fracturing process creates fractures **108** along the formation **155** to enhance fluid flow into the production casing **130**. Where the natural or hydraulically-induced

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fracture plane(s) of a formation are vertical, a horizontally completed wellbore (portion **190**) allows the production casing **130** to intersect multiple fracture planes. Hydraulic fracturing operations typically comprise injecting viscous fluids (usually shear thinning, non-Newtonian gels or emulsions) into the formation at such high pressures and rates that the reservoir rock fails and forms a network of fractures. The fracturing fluid is typically mixed with a granular proppant material such as sand, ceramic beads, or other granular materials. The proppant serves to hold the fracture(s) open after the hydraulic pressures are released. The combination of fractures and injected proppant helps increase the flow capacity of the treated reservoir.

[0086] While Figure 1 illustrates a well that has been fractured by hydraulic fracturing operations, those skilled in the art would understand that the present methods and techniques would have equal utility in maintaining and operating downhole wireless networks in wellbores that have not undergone hydraulic fracturing operations.

[0087] A downhole telemetry system is provided at the well site **100** of Figure 1. The telemetry system uses a series of communication nodes **180** arranged along the length of a conduit and/or tubular in the wellbore. In some embodiments, the communication nodes may be placed or positioned along the outer diameter of the vertically and/or horizontally disposed casing strings **110**, **120**, and/or **130**. In some embodiments, the communication nodes may be recessed within the pipe body, placed internally within the pipe body, at cross-sectional ends of the pipe joint, and/or positioned inside of the pipe through bore, and combinations thereof. For example, communication nodes may be placed on each pipe joint or casing joint, or may be placed at selected locations along every second or every third pipe joint. In some embodiments, some pipe joints receive two or more communication nodes.

[0088] Preferably, the communication node **180** is an independent wireless communication device that is designed to be attached to an external surface of the conduit or tubular member, but may also be attached to an inner surface, an end surface (e.g., on the cross-sectional end face of a connection), embedded within a wall of the conduit or tubular member, or combinations thereof. There are benefits to the use of an externally-placed communication nodes that use acoustic waves. For example, such a node will not decrease the effective inner diameter of the conduit or tubular member which could interfere with passing subsequent assemblies or tubulars through the internal bore of the conduit or tubular member. Further, installation and mechanical attachment of the communication node to the external surface can be readily assessed and adjusted.

[0089] The communication nodes are designed to attach to the wall of the conduit or tubular

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member, such as the casing or pipe. For example, the communication node may be pre-welded onto the wall of the conduit or tubular member. Alternatively, the communication node may be glued using an adhesive such as epoxy. In some embodiments, it may be preferred that the communication nodes are configured to be selectively attachable to and/or detachable from the conduit or tubular member by mechanical means at the well site. This may be done, for example, through the use of clamps. For example, a clamping system can be used that would allow a drilling or service company to mechanically connect/disconnect the communication nodes along the tubular body as the tubular body is being run into a wellbore.

[0090] In the arrangement of Figure 1, the communication nodes **180** may represent a plurality of subsurface communication nodes **180**. Each of the subsurface communication nodes **180** is configured to receive and then transmit data packets along the length of the wellbore **150**, such as from the subsurface formation **155** up to the surface **101**. Each data packet comprises a number of tones, which in a preferred embodiment are pulses at selected acoustic frequencies. Preferably, the acoustic frequencies are between about 50 kHz and about 1 MHz, from about 50 kHz to about 500 kHz, from about 60 kHz to about 250 kHz, from about 65 kHz to about 200 kHz, from about 70 kHz to about 175 kHz, from about 75 kHz to about 150 kHz, from about 80 kHz to about 125 kHz, from about 85 kHz to about 115 kHz, or from about 87 kHz to about 100 kHz. The tones may be pulses of a specified duration, or alternatively may be of indeterminate, continuous, or indefinite duration.

[0091] The communication nodes also include one or more topside communication nodes **182**. In Figure 1 only one topside communication node is shown; however, in some embodiments, two or more topside communication nodes may be used. The topside communication node **182** is placed closest to the surface **101**. The topside node **182** is configured to receive data packets from the upper-most of the subsurface communication nodes **180**. Thus, data packets are delivered from the subsurface up to the topside communication node **182**, in a node-to-node arrangement, by the plurality of communication nodes **180**. The topside communication node **182** is typically configured to receive the data packets from the plurality of communication nodes **180** and convert the data packets to electrical and/or optical signals which are then relayed on to a receiver **170** at the surface **101**. The topside communication node **182** may be above grade (i.e., above the surface) or below grade (i.e., below the surface). In preferred embodiments, the topside communication node **182** is actually connected to the well head **160**.

[0092] The well site **100** illustrates a receiver **170**. The receiver **170** comprises a processor

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172 that receives the signals sent from the one or more topside communication nodes **182**. The processor **172** may include discrete logic, any of various integrated circuit logic types, or a microprocessor. The receiver **170** may also include a screen and a keyboard **174** (either as a keypad or as part of a touchscreen). The receiver **170** may also be an embedded controller with neither screen nor keyboard which communicates with a remote computer via cellular modem, satellite, Wi-Fi, telephone lines, or other means of communication. In one aspect, the processor **172** may be part of a multi-purpose "smart phone" having one or more applications specific to the disclosed aspects, as well as wireless connectivity.

[0093] The signals may be received by the receiver **170** through a wire (not shown) such as a co-axial cable, a fiber optic cable, a USB cable, or other electrical or optical communications wire. Alternatively, the receiver **170** may receive the signals from the topside node **182** wirelessly through modem or transceiver or other wireless communications link. In some embodiments, the receiver **170** may receive electrical signals via a so-called Class 1, Division 1 conduit, that is, a housing for a wire as defined by NFPA 497 and API 500 for operations in an electrically classified area. Alternatively, data can be transferred from the topside node to a receiver via an electromagnetic (RF) wireless connection. In some embodiments, infrared or microwave signals may also or alternatively be used.

[0094] The signals, and the data embedded therein as obtained from the various communication nodes, may then be used by the wellbore operator to monitor and/or optimize the hydrocarbon development or hydrocarbon production operations with the wellbore. For example, the obtained signals and data may be beneficial for enhancing hydrocarbon operations, such as optimizing stimulation operations as described further below.

[0095] The communication nodes **180** in Figure 1 may be of various configurations, such as the communication node **255** illustrated in Figure 2A or communication node **200** illustrated in Figure 2B. In general, the communication nodes comprise an elongated body that supports one or more power sources and an electro-acoustic transducer. The electro-acoustic transducer is associated with a transceiver that receives data packets transmitted at acoustic frequencies and re-transmits the packets at the same or at a different frequency than the received acoustic frequency to the next communication node. Thus, the electro-acoustic transducer in each node allows data packets to be sent node-to-node up the wellbore using acoustic vibrations. Beneficially, the subsurface communication nodes do not require a wire or cable to transmit data or other information to the surface.

[0096] Figure 2A is a diagram of an exemplary communication node **255**. The

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communication node **255** may include a housing **260** along with a central processing unit ("CPU") **270**; memory **275**, which may include instructions or software to be executed by the CPU **270**; one or more encoding components **285**; one or more decoding components **290**; a power component **295**; and/or one or more sensing components **280**; all of which communicate via a bus **216**.

[0097] The power component **295** is generally configured to provide power to the components within the communication node **255**. The power component may include one or more batteries, capacitors, super-capacitors, fuel cells, or other energy storage components. The batteries and/or fuel cells may or may not be rechargeable.

[0098] The CPU **270** may be any general-purpose CPU, although other types of architectures of CPUs may be used as long as the CPU **270** supports the operations of the communication nodes described herein. In one or more embodiments, the CPU **270** may be a system-on-chip ("SOC"), programmable system-on-chip ("PSOC"), digital signal processor ("DSP"), application specific integrated circuit ("ASIC"), microprocessor, microcontroller, single processor, multiple processors (including different types/speeds), discrete processor, field programmable gate array ("FPGA") and/or other processor-like device. Further, the communication node may include a clock or the CPU **270** may include and/or operate at different effective clock speeds, such as low-frequency and/or high-frequency. The effective clock speed is the clock speed at which the processor operates after inclusion of applicable clock multipliers or clock dividers. The CPU **270** may execute the various logical instructions according to disclosed aspects and methodologies. For example, the CPU **270** may execute machine-level instructions for performing processing according to aspects and methodologies disclosed herein.

[0099] The memory **275** may include random access memory ("RAM"), such as static RAM ("SRAM"), dynamic RAM ("DRAM"), synchronous DRAM ("SDRAM"), or the like, read only memory ("ROM"), such as programmable ROM ("PROM"), erasable PROM ("EPROM"), electronically erasable PROM ("EEPROM"), NAND flash, NOR flash, or the like.

[0100] To manage the communications, the communication node **255** uses the one or more encoding components **285** and one or more decoding components **290** within the housing **260**. The encoding components **285**, which may include one or more transducers, may be disposed within the housing **260** and may be configured to generate acoustic tones and/or to induce an acoustic tone on a tone transmission medium. The one or more decoding components **290**,

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which may include one or more transducers, may be disposed within the housing **260** and may be configured to receive acoustic tones from the tone transmission medium. The encoding **285** and decoding **290** components may include instructions stored in memory and used to perform the generation of the acoustic tones or decoding of the acoustic tones. In one or more embodiments, the encoding component **285** and the decoding component **290** may use the same transducer.

[0101] The one or more sensing components **280** may be configured to obtain sensing data (such as measurement data) and communicate the data to the transducer for communication to the other communication nodes. By way of example, the sensing components **280** may be configured to obtain pressure measurements, temperature measurements, fluid flow measurements, vibration measurements, resistivity measurements, capacitance measurements, strain measurements, acoustic measurements, stimulation and/or hydraulic fracture properties measurements, chemical measurements, position measurements, and/or other suitable measurements. Additional examples of suitable sensing components are described with reference to Figure 2B.

[0102] Figure 2B provides another exemplary configuration of a communication node **200** and shows a cross-sectional view of the communication node **200** along its longitudinal axis. The communication node **200** includes a housing **210**, such as a fluid-sealed housing. The housing **210** is designed to be attached to an outer wall of a joint of a wellbore conduit or tubular member as described above. The communication nodes may be specially designed to withstand the corrosion and environmental conditions (e.g., high temperature, high pressure) of the wellbore. For example, the communication nodes may include steel, fluid-sealed housings for holding the electronics (e.g., batteries and/or electro-acoustic transducers). In some embodiments, the steel material is a corrosion resistant alloy. In some embodiments, it may be desirable to metallurgically match the housing of the communication node with that of the conduit or tubular member to aid in avoiding galvanic corrosion at the coupling.

[0103] The housing **210** includes an outer wall **212**. The wall **212** is dimensioned to protect internal electronics for the communication node **200** from wellbore fluids and pressure. In some embodiments, the wall **212** may have a thickness of less than 0.5 inches, such as from 0.01 inch to 0.5 inches, or from about 0.01 inch to about 0.4 inch, or from 0.1 inch, to about 0.3 inch, or be about 0.2 inches (0.51 cm) in thickness. The housing **210** optionally also has a protective outer layer **225**. The protective outer layer **225** resides external to the wall **212** and provides an additional thin layer of protection for the electronics. In some embodiments, it

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may be desirable to fabricate the wall **212** of a material or materials designed to enhance the acoustic response of the transducers in the disclosed telemetry system. This may be accomplished by selecting a material and/or thickness of the wall **212** to coincide with or be complementary to the frequencies expected to be used by the telemetry system. For example, the thickness of the one or more layers of material comprising wall **212** may be selected to be at a fraction of a wavelength given the acoustic velocity of sound through the material.

[0104] The communication node **200** may be of any size practical for the downhole environment. For example, the communication node may be from about 12 to 16 inches in length as it resides along the tubular body. The housing **210** of the communication node may be 8 to 10 inches in length, and each opposing shoe **250** may be 2 to 5 inches in length. Further, the communication node may be about 1 inch in width and 1 inch in height. The base of the communication node may have a concave profile that generally matches the curvature of the tubular body.

[0105] A bore **205** is formed within the wall **212**. The bore **205** houses the electronics, such as a battery **230**, a power supply wire **235**, a transceiver **240**, and a circuit board **245**. The circuit board **245** will preferably include a micro-processor or electronics module that processes received data packets. An electro-acoustic transducer **242** is provided to convert acoustical energy to electrical energy (or vice-versa) and is coupled with outer wall **212** on the side attached to the tubular body. The transducer **242** may be in electrical communication with one or more sensors **232** and/or **234**.

[0106] The sensor may be, for example, pressure sensors, temperature sensors, or microphones, or any other sensor as described herein or with reference to Figure 2A. The sensor **232** and/or **234** sends signals to the transceiver **240** through a short electrical wire or through the printed circuit board **245**. Signals from the sensor **232** are converted into acoustic tones using an electro-acoustic transducer **242**, which are then sent by the transceiver **240** as one or more data packets. For example, the sensor will measure a piece of data, such as a temperature measurement, strain measurement, acoustic noise data, geophone data, etc., the transducer then converts the piece of data (e.g., the temperature) into a series of acoustic tones representative of the data. The acoustic tones are then sent by the transceiver as one or more data packets onto the next communication node.

[0107] In Figure 2B, the sensor **232** resides within the housing **210** of the communication node **200**. However, in some embodiments there may not be a sensor **232**, and instead a sensor **234** may reside external to the communication node **200**. The external sensor may be above or

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below the communication node **200** along the wellbore. In Figure 2B, a dashed line is provided showing an extended connection between the sensor **234** and the electro-acoustic transducer **242**.

[0108] While Figure 2B illustrates sensors associated with the communication node **200**, in the network illustrated in Figure 1 it is not required that all of the communication nodes **180** possess or be associated with a sensor. That is, some communication nodes **180** may have sensors, while others may not and may simply be used to transmit information up and down the wellbore.

[0109] Returning to Figure 2B, the communication node **200** also, optionally, includes a shoe **250**. For example, the node **200** may include a pair of shoes **250** disposed at opposing ends of wall **212**. Each of the shoes **250** provides a beveled face that helps prevent the node **200** from hanging up on an external tubular body or the surrounding earth formation, as the case may be, during run-in or pull-out. The shoes may have a protective outer layer **222** and an optional cushioning material under the outer layer **222**.

[0110] As seen in Figure 2B, the communication node has an independent power source **230**. The independent power source **230** may be, for example, batteries or a fuel cell. Having a power source that resides within the housing of the communication nodes avoids the need for passing electrical connections through the housing, which could compromise fluid isolation. In some embodiments, the power source may be a rechargeable power source, such as a rechargeable battery.

[0111] The internal components of each communication node may include a protective layer that encapsulates said internal components. This protective layer may provide additional mechanical durability and moisture isolation. The communication nodes may also be fluid sealed within the housing to protect the internal electronics from exposure to undesirable fluids and/or to maintain dielectric integrity within the voids of a housing. One form of protection for the internal electronics is available using a potting material.

[0112] As described above with reference to Figures 1, 2A, and 2B, each communication node can have the capability of sending and receiving data packets at acoustic frequencies, so that the downhole wireless network is able to transmit data in a node-to-node arrangement from the subsurface to the surface. In some embodiments, the acoustic telemetry data transfer is accomplished using a multiple frequency shift keying ("MFSK") modulation method. Although MFSK is well-suited for application in the downhole wireless networks described

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herein, its use is as an example and is not intended to be limiting. That is, it is known that various alternative forms of digital data modulation are available, for example, frequency shift keying ("FSK"), multi-frequency signaling, phase shift keying, pulse position modulation, and on-off keying.

[0113] Thus, tones generated by the electro-transducer within a communication node pass through the communication node's housing to the tubular body (such as the production or casing string), and propagate along the tubular body to other communication nodes. Each tone is then re-transmitted in a node-to-node arrangement up the wellbore until it reaches the topside communication node and the well operator. The re-transmitted signal represents the same sensor data originally transmitted by the first sensing communication node.

[0114] In some embodiments, the data packets transmitted at acoustic frequencies may be generated and received by magnetostrictive transducer(s) comprising a coil wrapped around a core as the transceiver. In some embodiments, the data packets transmitted at acoustic frequencies are generated and received by a piezo-electric ceramic transducer. In either case, the electrically encoded data is transmitted at acoustic frequencies that are carried through the wall of the tubular body in the wellbore.

[0115] Acoustic telemetry along tubulars is characterized by multi-path transmission or reverberation which persists for a period of milliseconds, and may persist for tens to hundreds of milliseconds. As a result, a transmitted tone of a few milliseconds duration determines the dominant received frequency for a period of time of additional milliseconds. Preferably, the communication nodes determine the transmitted frequency by receiving or "listening to" the received acoustic tones for a period of time corresponding to the tones' reverberation time, which is typically longer than the tones' transmission time. Specifically, the tones' transmission time should be long enough so that the frequency spectrum of the tone has negligible energy at the frequencies of neighboring tones, and the listening time must be long enough for the multi-path transmission to become substantially reduced in amplitude. For example, the duration of a tone's transmission time may be about 5-10 milliseconds (ms), and then the transmitter may remain silent for a wait time of about 20-30 ms before sending the next tone. The receiver, however, would listen for the sum of the tone's transmission time and the wait time to determine each transmitted frequency, using the long reverberation time to make the frequency determination more certain. Beneficially, the energy required to transmit data is reduced by transmitting for a short-period of time and exploiting the multi-path to extend the listening time during which the transmitted frequency may be detected. Additionally or

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alternatively, other strategies and techniques may be employed to improve the audibility of the tones comprising the data packet, such as acoustic spectrum-constrained detection, time domain selective detection, and sliding alphabet. These strategies may be more fully described in, for example, commonly-owned U.S. Patent No. 10,167,716 and U.S. Patent Application No. 15/666,348.

[0116] For example, as described above, an MFSK modulation may be employed where each tone in a data packet is selected from an alphabet of 16 tones, so that it represents 4 bits of information. With a listening time of 50 ms, for example, the data rate is 80 bits per second.

[0117] The tones in a data packet are selected to be within a frequency band where the signal is detectable above ambient and electronic noise at least two nodes away from the transmitter node so that if one node fails, it can be bypassed by transmitting data directly between its nearest neighbors above and below. For example, the tones may be evenly spaced in period within a frequency band of from about 50 kHz to about 1 MHz, from about 50 kHz to about 500 kHz, from about 60 kHz to about 250 kHz, from about 65 kHz to about 200 kHz, from about 70 kHz to about 175 kHz, from about 75 kHz to about 150 kHz, from about 80 kHz to about 125 kHz, from about 85 kHz to about 115 kHz, or from about 87 kHz to about 100 kHz.

[0118] Preferably, the nodes employ a "frequency hopping" method where the last transmitted tone is not immediately re-used. This prevents extended reverberation from being mistaken for a second transmitted tone at the same frequency. For example, 17 tones are used for representing data in an MFSK modulation scheme; however, the last-used tone is excluded so that only 16 tones are actually available for section at any time.

[0119] Any extraneous noise in the tones of a data packet may be moderated by using well-known conventional analog and/or digital signal processing methods. The noise removal and signal enhancement may involve conveying the tones through a signal conditioning circuit using, for example, a bandpass filter.

[0120] Returning to Figure 1, each communication node is associated with a specific conduit or tubular member, and may be associated with a specific joint of pipe. That joint of pipe, in turn, has a known location or depth along the wellbore. Each data packet may include one or more node identifiers to indicate where the data packet originated, which node is the intended recipient, and/or which node is the ultimate destination for the information conveyed

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in the data packet. The data packet is relayed node-to-node from the communication nodes **180** in the subsurface to the one or more topside nodes **182** and on to the receiver **170**.

[0121] As such, a data packet has at least an identifier (such as a node identification number (ID) of the sending node and/or the receiving node) for the subsurface communication node that originally transmitted the signal. When the data packet reaches the receiver at the surface, the signal is processed. This involves identifying which communication node the data packet originated from, and then determining the location of that communication node along the wellbore.

[0122] The data packet may further comprise data obtained from one or more sensors associated with the communication node. As described above, the communication node may contain or be associated with one or more sensors. The sensors may be, for example, fluid velocity measurement device, a temperature sensor, a pressure sensor, a fluid density sensor, a microphone, an ultrasound sensor, a Doppler shift sensor, a chemical sensor, an imaging sensor, an impedance sensor, an attenuation sensor, a fluid resistivity sensor, and/or other useful type of sensor. In general, the sensor provides readings to the transceiver which are converted into tones using an electro-acoustic transducer, that are then sent by the transceiver as part of a data packet. Thus, the communication node may be configured to receive readings from the associated sensor and transmit data packets indicative of readings taken by the sensor.

[0123] To conserve power, the communication nodes may be configured to operate in various modes, such as a sleep mode and an operational mode. For example, the communication node may include a sleep mode that is a low power, non-responsive energy saving state. The sleep mode may be a low energy mode, which limits the availability of the communication node to receive transmitted data packets. The operational mode may be a mode of operation that involves running the processor in one or more of an active mode or a listening mode. The listening mode may involve monitoring for received data packets, while the active mode may involve transmitting data packets, obtaining measurement data, and/or storing measurement data from sensors.

[0124] The communication nodes may also communicate with other communication devices (other than the other communication nodes). For example, the communication nodes may be configured to be able to communicate with a communication device such as a hydrophone, or other downhole tool. The communication device may communicate with the communication nodes with low-frequency signals or high-frequency signals, and may be used to exchange data or instructions with the communication nodes. The low-frequency

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communication nodes may be configured to transmit and/or receive at frequencies less than or equal to (≤) 200 kHz, ≤ 100 kHz, ≤ 50 kHz, or ≤ 20 kHz. In particular, the low-frequency communication nodes may be configured to transmit and/or receive at frequencies in the range between about 100 Hz and about 20 kHz, or between about 1 kHz and about 20 kHz, or between about 5 kHz and about 20 kHz. Other configurations may include low-frequency communication nodes, which may be configured to transmit and/or receive at frequencies in the range between about 100 Hz and about 200 kHz, or between about 100 Hz and about 100 kHz, or between about 1 kHz and about 200 kHz, or between about 1 kHz and about 100 kHz, or between about 5 kHz and about 100 kHz, or between about 5 kHz and about 200 kHz. The communication nodes may also include high-frequency communication nodes configured to transmit and/or receive at frequencies greater than (>) 20 kHz, > 50 kHz, > 100 kHz or > 200 kHz. Also, the high-frequency communication nodes may be configured to transmit and/or receive at frequencies in the range between greater than about 20 kHz and about 1 MHz, or greater than about 20 kHz and about 750 kHz, or greater than about 20 kHz and about 500 kHz. Other configurations may include high-frequency communication nodes, which may be configured to transmit and/or receive at frequencies in the range between greater than about 100 kHz and about 1 MHz, or between greater than about 200 kHz and about 1 MHz, or between greater than about 100 kHz and about 750 kHz, or between greater than about 200 kHz and about 750 kHz, or greater than about 100 kHz and about 500 kHz, or between greater than about 200 kHz and about 500 kHz.

[0125] When there is a failure along the downhole wireless communications network, it may be desirable to obtain the data from the network and also to repair the network. This failure could be due to an error in the programming of the software on the node, or it could be a hardware failure. The failure may be a local failure, involving only a few nodes, or may be a regional failure, where many nodes are affected. An example of a local failure may occur when two or more communication nodes do not communicate with each other after a certain number of attempts (e.g., three, or four, or five, or more failed attempts to communicate).

[0126] In some instances, the full system may also need to be re-evaluated when there are changes in the acoustic environment within the wellbore. For example, cementing, fracking, and/or injections within the well can alter the acoustic environment within the well. Also, over time simply producing hydrocarbons can alter the acoustic environment within the well. The changes in the environment can then lead to changes in the acoustic conditions along the tubular member, which can affect the reliability and accuracy of communications between the

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communication nodes. Thus, the communication nodes within the network may need to be re-programmed to change their functionality. For example, a communication node may be reprogrammed to filter out background noise (e.g., production noise) that did not exist when the network was first put in place.

[0127] The present methods and systems use a downhole tool that includes a communications device to repair the network, maintain the network, optimize the network, or to help collect data from various portions of the network, which in one aspect may include a severed portion of the network. For example, the downhole tool may include an associated signal receiver. The signal receiver may be configured to receive the data signals from various communication nodes as the downhole tool passes the nodes in the wellbore.

[0128] As described above, the present methods and techniques may be useful for operating and maintaining downhole wireless networks, such as those described with reference to Figures 1, 2A, and 2B. For example, Figure 5 is an exemplary flow chart **500** in accordance with an embodiment of the present techniques. The flow chart **500** is a method and system for operating and maintaining a downhole wireless network. In general, the method may comprise detecting a failure in the downhole wireless network and using a communications device, such as a hydrophone, to correct the error and/or to bypass the malfunctioning communication nodes in the downhole wireless network. It is to be understood that Figure 5 is merely representative of one way of using a hydrophone in a downhole environment, and that other uses of a hydrophone are not to be excluded from the scope of the disclosed aspects.

[0129] While not illustrated in Figure 5, the method may first comprise providing a downhole wireless network as described herein. The network may comprise a series of communication nodes that are attached to a tubular in the wellbore, where adjacent communication nodes are configured to communicate by acoustic signals transmitted through the tubular.

[0130] Once the downhole wireless network is provided, the method may comprise operating the downhole wireless network to communicate data signals from the subsurface to the surface. At block **502** a communication failure is detected in the downhole wireless network. The communication failure may be identified by the operator when data signals are no longer received below a certain point (or depth) of the wellbore. As such, the operator may either conclude that (a) a failure or break in the wellbore or casing has occurred, or (b) one or more communication nodes in the network are malfunctioning. In some embodiments, the downhole wireless network may share failure information with the downhole tool to speed

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detection of the specific failure and/or facilitate improved mitigation.

[0131] At block **504** the location of the error is identified. Identifying the location of the error may entail examining the data packets to identify the deepest communication node (i.e., the communication node farthest from the surface) from which the data packet can be determined to have been transmitted. For example, referring to Figure 3A, the data packets that are received at the topside can be analyzed to determine that Node 24 is the deepest communication node from which a data packet was received. Thus, the operator can determine that there is a communication error at Node 25.

[0132] At block **506** a downhole tool, such as a communications device, may be lowered into the wellbore to the location of the error. For example, a downhole tool that contains a communications device may be run into the wellbore. The downhole tool may be run into the wellbore using a working string (such as a coiled tubing string, a jointed working string, a slick line, or an electrical line) or may be an autonomous tool that is wireless. Thus, the downhole tool may be conveyable within the wellbore via a tubing string, coil tubing, wireline, electrical wireline, autonomously, or pumped in by a fluid. In some embodiments a downhole tool such as that illustrated in Figure 4 may be used.

[0133] In preferred embodiments, the downhole tool allows for two-way communication with the subsurface communication nodes. For example, the downhole tool may be a long-range ultrasonic hydrophone that operates at a frequency of from about 50 kHz to about 1 MHz, from about 50 kHz to about 500 kHz, from about 60 kHz to about 250 kHz, from about 65 kHz to about 200 kHz, from about 70 kHz to about 175 kHz, from about 75 kHz to about 150 kHz, from about 80 kHz to about 125 kHz, from about 85 kHz to about 115 kHz, or from about 87 kHz to about 100 kHz. In some aspects, the downhole tool may communicate in multiple frequency bands, including non-overlapping frequency bands, to support communication with various classes of devices. Such use of multiple frequency bands may also enable parallel reception and/or transmission on multiple channels for performance or reliability reasons. Additionally or alternatively, one or more frequency bands may be used for sensing operations while another frequency band or bands may be used for communications.

[0134] Preferably, the downhole tool is lowered through the production string and is able to communicate with communication nodes that are exterior of the wellbore casing. In such instances, the downhole tool should be designed and configured such that it is able to communicate through layers of cement, mud, the tubular (i.e., piping and/or casing), as well as the formation.

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[0135] An exemplary downhole tool **400** that may be used is illustrated in Figure 4. The downhole tool comprises a housing **408** that holds piezoelectric transducers and sensors **416**, a power supply **414**, a two-way communications transceiver **412**, and an electronics board **410**. Alternatively, the downhole tool may be powered by a surface power supply (not shown) via a power cable incorporated into a wireline cable **406**. In an aspect, the housing holds one or more piezoelectric transducers and sensors **416** that may be positioned around or within the housing and oriented to face upwards, downwards, and/or sideways. The electronics board **410** provides for a transducer interface, control electronics, signal generation / processing, data and telemetry system diagnostics, and data logging capabilities. The downhole tool may be lowered into the wellbore via the wireline cable **406** which may be connected to a truck interface unit **404**. The truck interface unit **404** may then have a wireless or wired connection to a control computer **402.**

[0136] Returning to Figure 5, the downhole tool comprising a communications device is lowered into the wellbore to the location of the error at block **506**. Optionally, at block **508** the downhole tool can be used to diagnose or troubleshoot the type of error that is occurring with the communication node. For example, the downhole tool can determine if the error is due to a power failure **510**, a mechanical failure **514**, or a programming / software failure **518**.

[0137] If the error is determined to be caused by a power failure **510** or a low battery in a communication node, the downhole tool can be used to attempt to recharge the battery in the malfunctioning node. For example, at block **512**, the downhole tool could be used to wirelessly recharge the battery. Alternatively, it could be determined to lower a different downhole tool into the wellbore that can recharge the battery in the communication node through electromagnetic pulses/waves sent through the wall of the casing.

[0138] If the error is determined to be caused by a programming or software failure **518**, the downhole tool can be used to reprogram the malfunctioning communication node. For example, the downhole tool may wirelessly transmit a new program / software code to the malfunctioning node at block **520**. This may be useful when there has been a change in the acoustic conditions within the wellbore, such that the communication node needs to be reprogramed to transmit data packets at a different frequency or to use different frequency keys, timings, configuration parameters, etc.

[0139] In some embodiments it may be determined that the error is a mechanical error **514** (e.g., a mechanical failure of the communication node's transceiver) that cannot be fixed. Similarly, it may be determined that the power failure **510** or software/programming failure

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518 is such that it cannot be fixed. In such instances, the downhole tool can be used to heal the network by bridging the gap between functioning nodes at block **516**. Referring to Figure 3B, the downhole tool may be lowered downhole to be near the malfunctioning nodes, Nodes 25 and 26. The downhole tool can then be used to collect data from Node 27 and transmit the data upstream to Node 24 from which it can be transmitted through the downhole wireless network to the surface. Alternatively, the downhole tool may collect the data from Node 27 and transmit the data up the wireline to the surface or use the low frequency capabilities of the downhole tool to acoustically transmit the data to the surface. Referring to Figure 5, once the tool is removed from the wellbore (if on a wireline) and necessary remedial actions taken, hydrocarbon fluids may then be produced from the wellbore at block **522**.

[0140] As described herein, the present methods and systems may be used to operate a downhole wireless network even though one or more communication nodes within the network have begun to malfunction. Further, the present methods and systems may additionally be used to reprogram nodes within the network, such that they are once again able to operate properly. In such a manner, the present methods and systems may be used to "heal" a damaged downhole wireless network. This can be advantageous as it can allow for the collection of data from functioning portions of the network that may be otherwise cut-off. Additionally, once the casing the communication nodes are placed on has been cemented into place, it is difficult if not impossible to physically access the nodes and repair them. As such, the present methods and systems can provide means for wirelessly correcting some problems and allowing malfunctioning communication nodes to operate properly again.

[0141] In some embodiments, the downhole tool may be used to maintain and/or optimize a downhole wireless network. For example, the downhole tool may be used to reprogram one or more communication nodes to provide new functionality even if the communication nodes are currently functioning properly. The communication nodes may be reprogrammed to be associated with a new wireless sensor, and thus be programmed to transmit data signals from the new sensor. The communication nodes may be instructed to receive and/or transmit at different frequencies, use different frequency keys, etc. The communication nodes may be queried by the downhole tool using a health check algorithm to analyze the status thereof. This may be done, for example, to determine its current software load, sense or estimate remaining battery life, determine effectiveness of acoustic communication in a particular portion of the wellbore, and the like. Thus, the downhole tool may be used to optimize communication settings of a communication node even if the software itself is not updated. Such optimization

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may be done in conjunction with profiling or based on data collected by communication nodes that suggests an increased risk of communication degradation or failure in the foreseeable future. Preventive maintenance of the network may be conducted by the downhole tool as acoustic conditions change over time, to keep the network running to a given performance or reliability standard.

[0142] According to other aspects of the disclosure, the downhole tool may act as a substitute topside node by directly transmitting data packets to selected communication nodes, possibly skipping multiple transmissions of data packets along the network to that point. Alternatively, the downhole tool may temporarily replace a communication node by assuming its identity or by otherwise replacing the communication capabilities of the communication node. As each communication node has a unique identifier assigned thereto, having the downhole tool temporarily assume the identity of a communication node maintains the integrity of the downhole wireless network without the need to reconfigure part or all of the network, thus saving significant time and energy of the communication nodes in the network. This also extends the life of a node-to-node communication network.

[0143] The hydrophone as disclosed herein has been discovered to be especially useful to enable two-way communication within a downhole wireless network. The hydrophone has been found to acoustically communicate with communication nodes through two or more layers of cement, tubulars, mud, or formation. The electroacoustic transducers inside the hydrophone are coupled to the outer wall of the hydrophone, which has an acoustically favorable thickness (e.g., some fraction of a wavelength of a frequency in the communication band given the acoustic velocity of sound through the hydrophone wall material). This placement allows for favorable communication, typically not in an omnidirectional manner. The hydrophone may communicate with nodes more than 400 feet away, thereby enabling direct access to multiple communication nodes in a single part of a wellbore. As typical communication nodes in an acoustic wireless network are designed to communicate only with adjacent communication nodes and therefore have a limited range of about 50 feet to about 120 feet, the hydrophone as implemented herein can provide additional communication capabilities within a downhole wireless network. The hydrophone may therefore be used as an additional participant in an established downhole wireless network. The hydrophone may also use its ultrasound telemetry capabilities to characterize a production or barrier tubular, and may be used to obtain information regarding drilling or production fluids. This characterization of tubulars and/or fluids may be further used to select transmission and/or telemetry settings to

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enhance network communications. Lastly, the hydrophone may be used to communicate with and/or control downhole tools such as sleeves, valves, and/or flow controllers which are likewise equipped with ultrasound telemetry functionality.

[0144] The disclosed aspects may be beneficially used in a multilateral well system, where at least a portion of a downhole wireless network is disposed within one or more of the lateral branches thereof. The downhole tool, including the hydrophone, may be run either with the upper completion (with wires to the surface) or as part of the toolstring, where the hydrophone would stop at the junction of the lateral branch and retrieve data from communication nodes installed in the lateral branch.

[0145] The disclosed aspects may also be used during fracturing operations. Communication nodes may be installed within one or more fracturing compartments, with the hydrophone installed in the plug-milling string. Upon reaching a plug, the hydrophone communicates with communication nodes within an adjacent fracturing compartment and obtains treatment pressure/temperature information, which can be valuable to receive real-time during fracturing operations. The milling string proceeds to mill out the fracturing plug, moves to the next fracturing plug, and repeats the same steps.

[0146] An advantage of using a downhole tool such as a hydrophone as disclosed herein is that it allows direct communication with communication nodes in a wireless network that would not otherwise be audible. The hydrophone permits more distant nodes to transmit at a lower amplitude than normal, thereby saving significant energy and extending the useful life of the distant nodes. The hydrophone may also be used to skip over a section of nodes that are in a sleep state and directly communicate with nodes having desired data. Because the hydrophone is directly connected to the surface, the hydrophone may therefore act as a substitute topside node. This also extends the life of a node-to-node communication network. The hydrophone may also transmit the commands necessary to place one or more communication nodes into a sleep state or a wake state. This also saves significant time and energy relative to having the communication nodes themselves issue sleep/wake commands to other nodes. The disclosed aspects permit communication with nodes that otherwise have too little remaining energy to communicate with the rest of a wireless network. This enables sensor data to be retrieved that would otherwise be lost. Additionally, the disclosed aspects permit faster data retrieval via bypassing a number of intermediary nodes that otherwise would have been needed for data retrieval without the use of the hydrophone.

[0147] It should be understood that the preceding is merely a detailed description of

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specific embodiments of the invention and that numerous changes, modifications, and alternatives to the disclosed embodiments can be made in accordance with the disclosure here without departing from the scope of the invention. The preceding description, therefore, is not meant to limit the scope of the invention. Rather, the scope of the invention is to be determined only by the appended claims and their equivalents. It is also contemplated that structures and features embodied in the present examples can be altered, rearranged, substituted, deleted, duplicated, combined, or added to each other. As such, it will be apparent, however, to one skilled in the art, that many modifications and variations to the embodiments described herein are possible. All such modifications and variations are intended to be within the scope of the present invention, as defined by the appended claims.

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CLAIMS:

1. A method for operating a downhole wireless network, comprising:

providing a downhole wireless network, where the downhole wireless network comprises a plurality of communication nodes spaced along a wellbore and attached to an outer surface of a tubular within the wellbore, where the communication nodes are configured to transmit data signals as acoustic waves from node-to-node up the wellbore to the earth's surface;

detecting a communication error in the downhole wireless network, where the data signals from at least one communication node is not received at the earth's surface;

identifying the location of the communication node that is causing the communication error;

lowering a downhole tool comprising a communications device into the wellbore to the location of the error;

transmitting the data signals from a communication node lower than the location of the error to the downhole tool; and

transmitting the data signals from the downhole tool to the earth's surface.

2. The method of claim 1, wherein each communication node of the plurality of communication nodes comprises:

a sealed housing;

an electro-acoustic transducer and associated transceiver residing within the housing, where the transceiver is configured to relay signals from node-to-node up the wellbore; and

an independent power source residing within the housing providing power to the transceiver.

3. The method of claim 1, wherein the communication nodes are spaced apart such that each joint of pipe in the tubular supports at least one communications node.

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4. The method of claim 1, wherein the communications nodes are spaced at an interval of from about 20 feet to about 40 feet.

5. The method of claim 1, wherein each of the communication nodes is designed to receive acoustic waves at a first frequency and then transmit the acoustic waves at a second frequency up the wellbore to a receiver at the earth's surface.

6. The method of claim 1, wherein one or more sensors reside within the housings of selected communications nodes.

7. The method of claim 1, wherein the electro-acoustic transducers within the selected communications nodes convert signals from the one or more sensors into acoustic signals for the associated transceivers.

8. The method of claim 1, wherein the downhole tool comprises a hydrophone.

9. The method of claim 8, wherein the hydrophone is an ultrasonic hydrophone.

10. The method of claim 8, wherein the hydrophone transmits signals at a frequency in the range of from 50 to 500 kHz.

11. The method of claim 1, wherein the downhole tool transmits the data signals to the earth's surface via a wireline.

12. The method of claim 1, wherein the downhole tool transmits the data signals to the earth's surface via long-range ultrasonic acoustic transmissions.

13. The method of claim 1, wherein the downhole tool transmits the data signals to the earth's surface by transmitting the data signals to a communication node above the location of

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the error and wherein the communication node then transmits the data signals in a node-to-node manner up the wellbore to the earth's surface.

14. The method of claim 1, further comprising using the downhole tool to determine the type of error that is occurring in the communication node.

15. The method of claim 1, further comprising wirelessly transmitting a new program from the downhole tool to the malfunctioning communication node.

16. A method for operating a downhole wireless network, comprising:

providing a downhole wireless network, where the downhole wireless network comprises a plurality of communication nodes spaced along a wellbore and attached to an outer surface of a tubular within the wellbore, where the communication nodes are configured to transmit data signals as acoustic waves from node-to-node up the wellbore to the earth's surface;

lowering a downhole tool comprising a communications device into the wellbore to a location associated with at least one identified communication node; transmitting signals from the downhole tool to the identified communication node,

whereby the signals operate to re-program the communication node.

17. The method of claim 16, wherein the signals from the downhole tool operate to re-program the communication node with a new filter to better filter out background noise.

Date Reçue/Date Received 2021-09-30

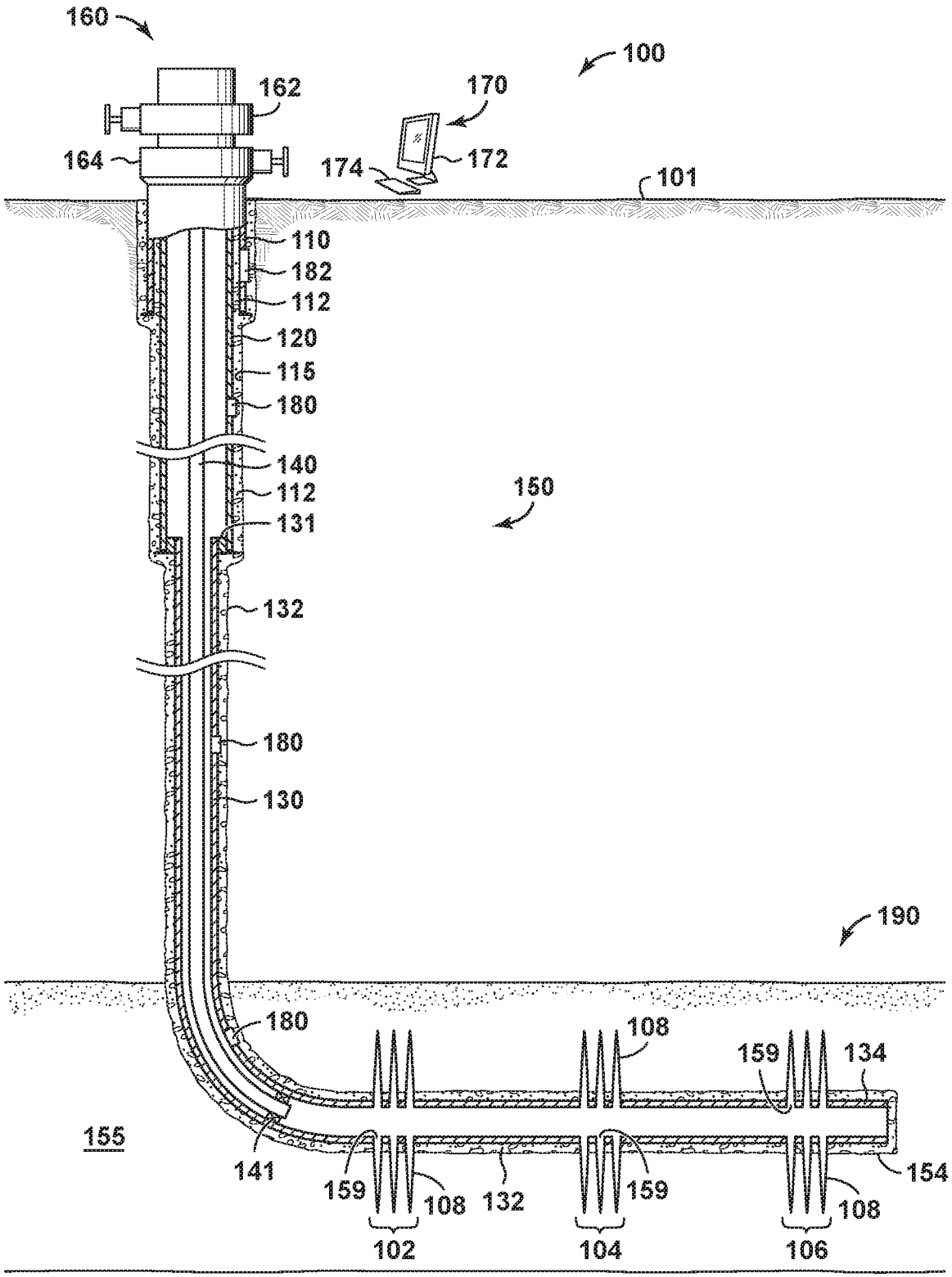

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FIG. 1

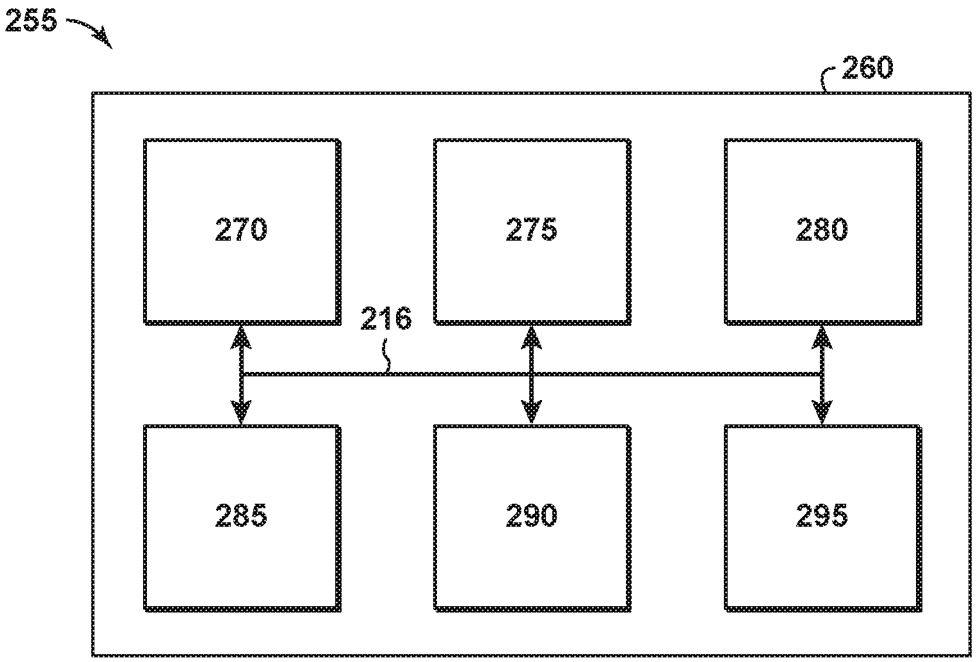

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FIG. 2A

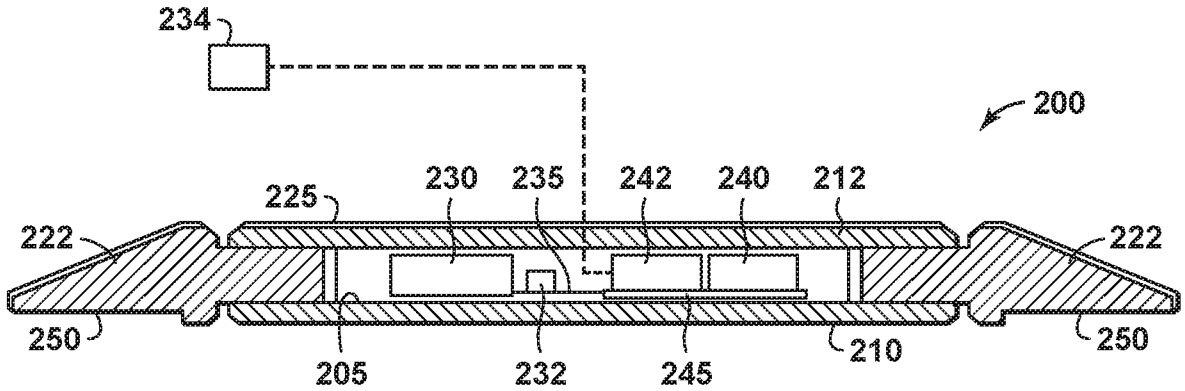

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FIG. 2B

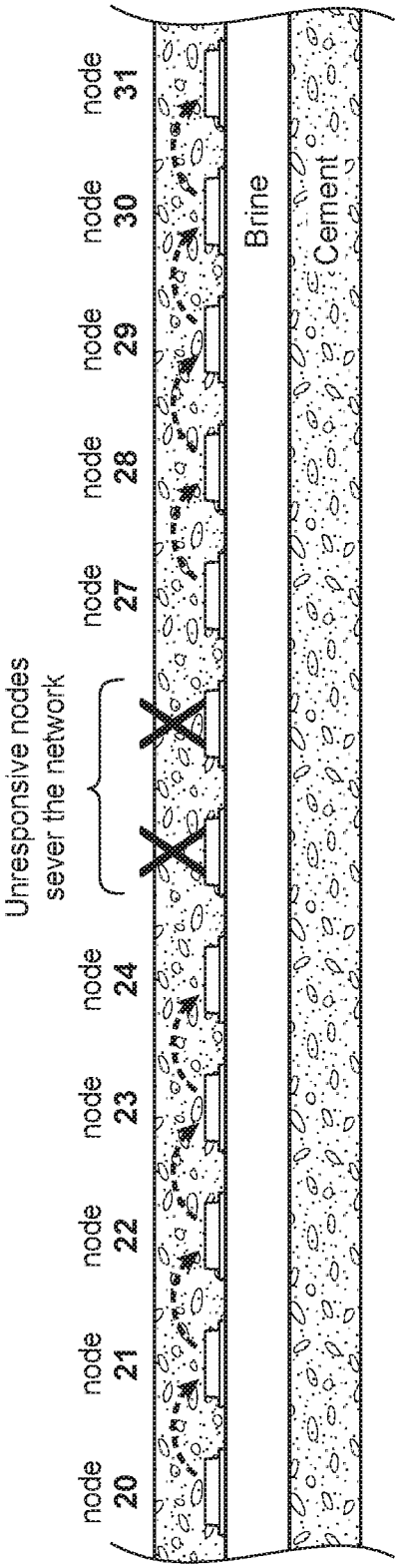

node 20
node 21
node 22
node 23
node 24
node 27
node 28
node 29
node 30
node 31
Unresponsive nodes sever the network
Brine
Cement

FIG. 3A

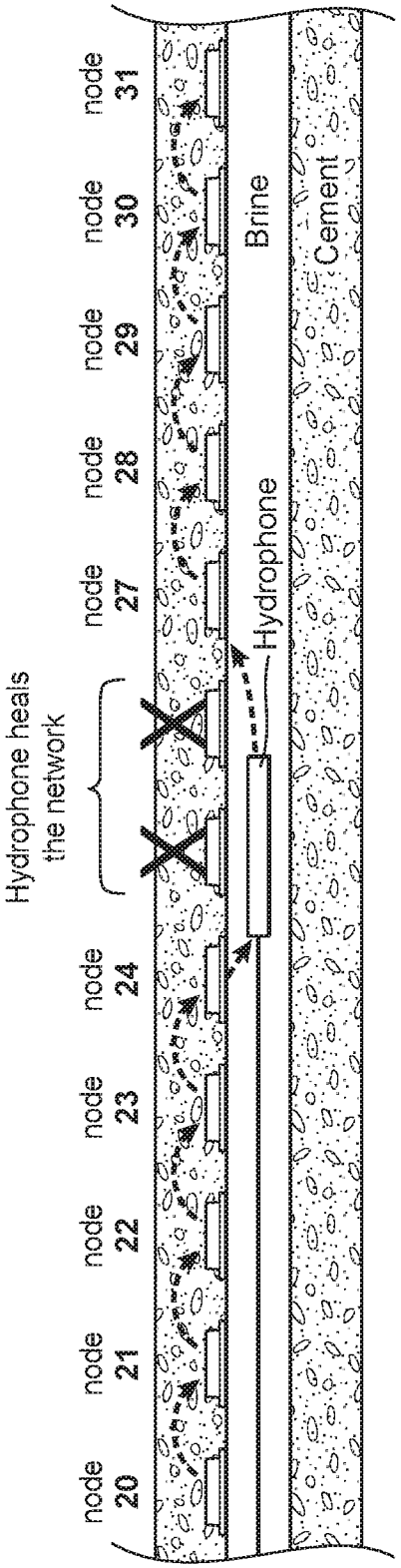

node 20
node 21
node 22
node 23
node 24
node 27
node 28
node 29
node 30
node 31
Hydrophone heals the network
Hydrophone
Brine
Cement

FIG. 3B

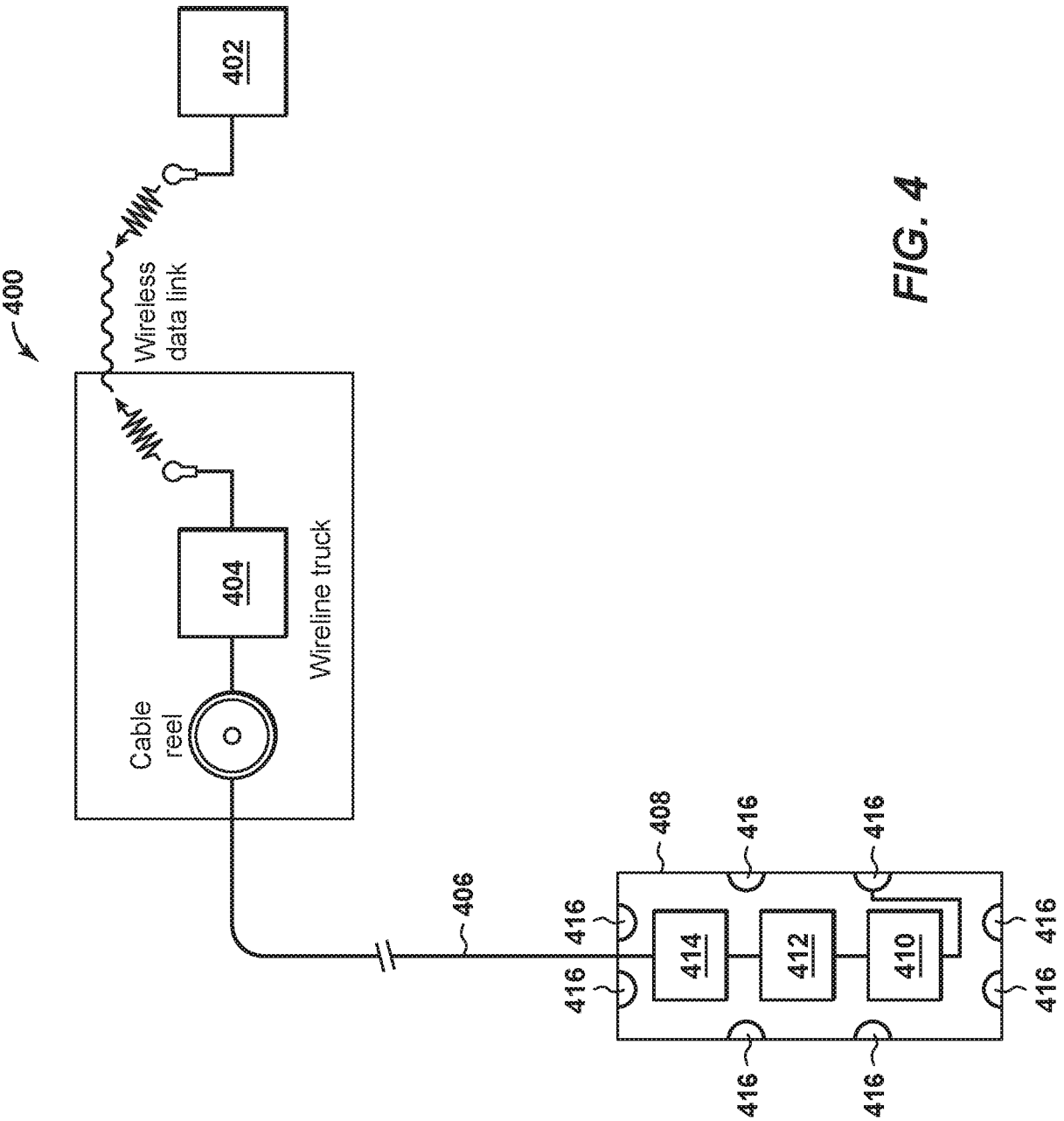

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Wireless data link
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Wireline truck
Cable reel
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FIG. 4

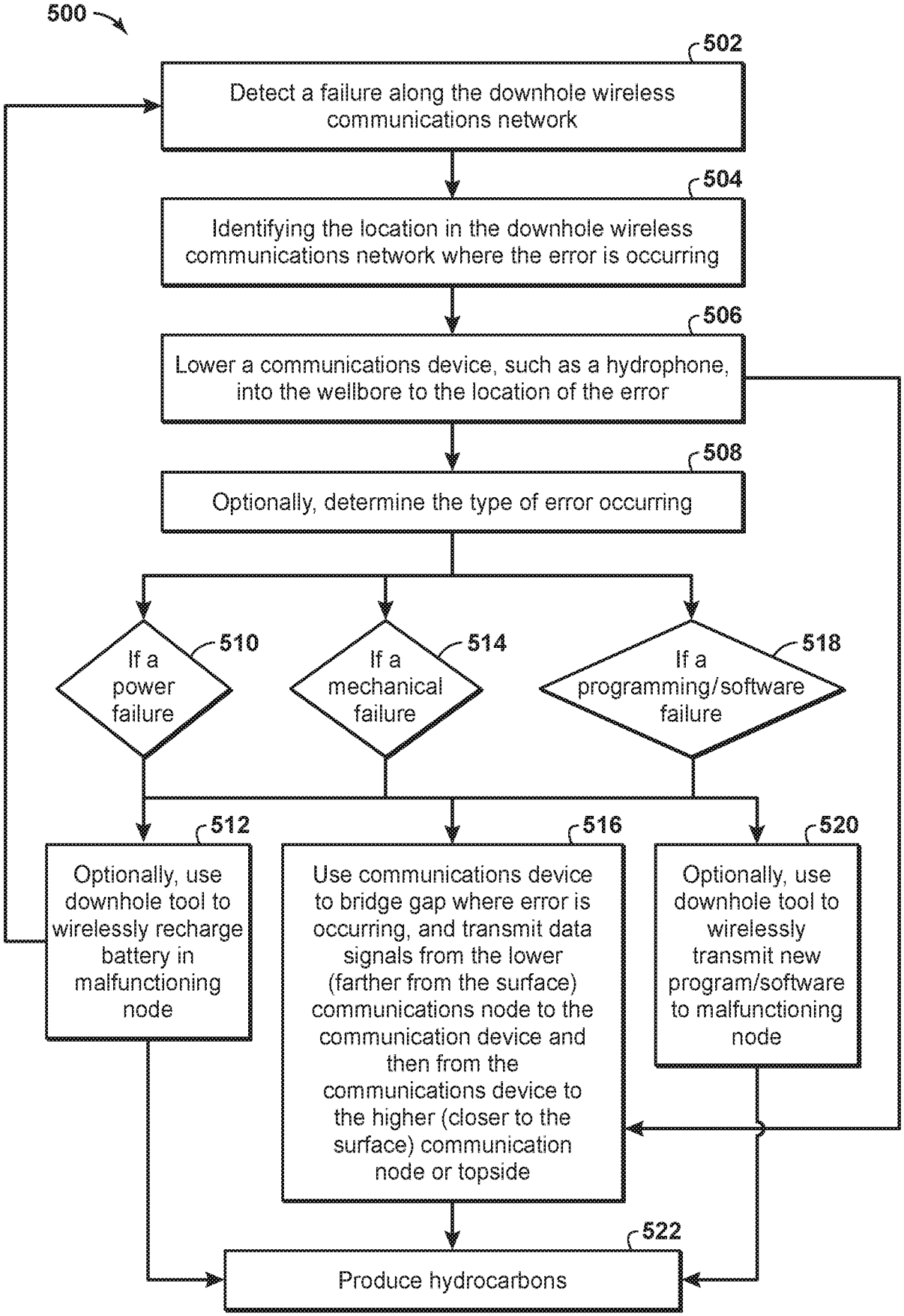
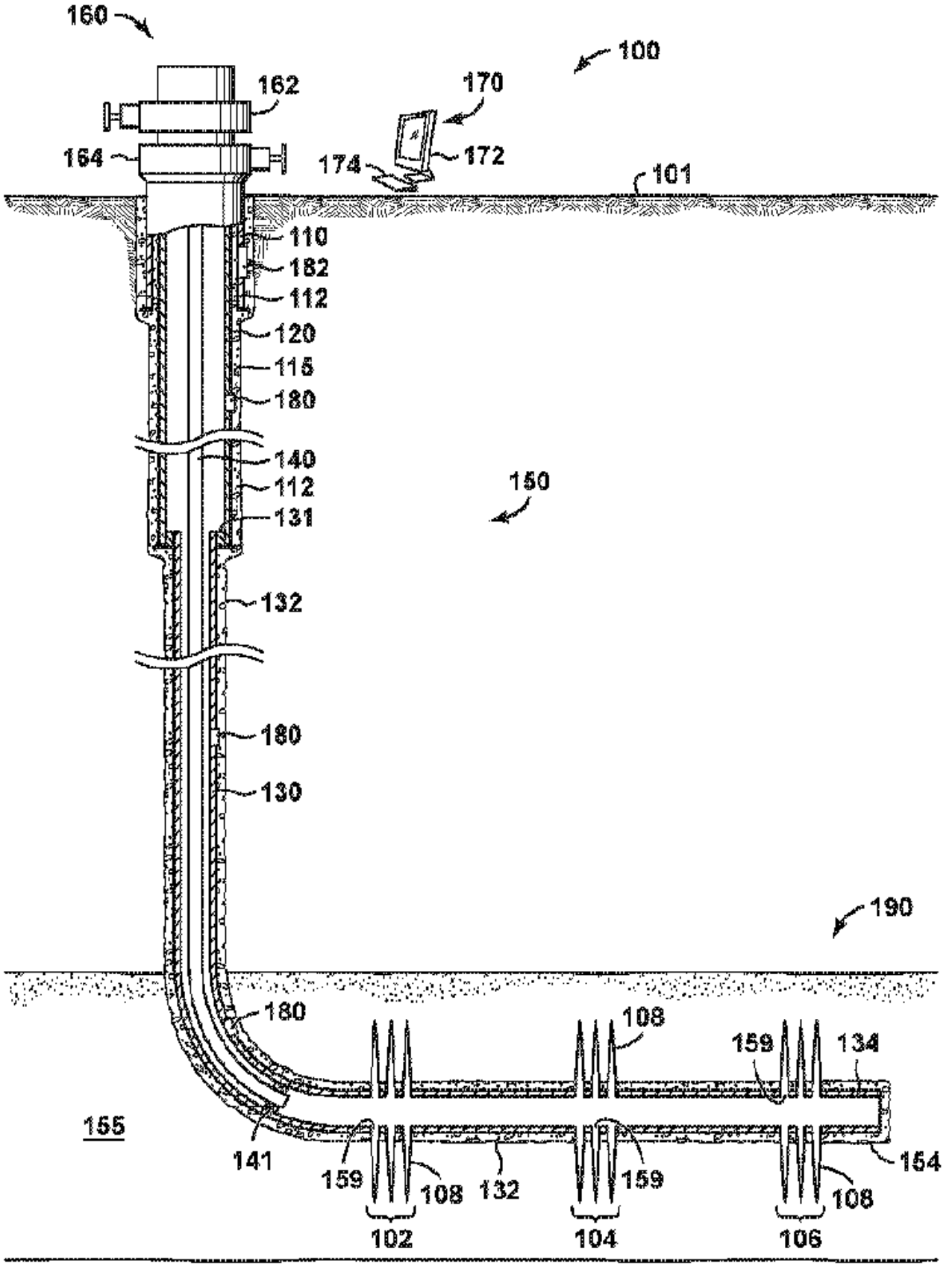

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502
Detect a failure along the downhole wireless communications network
504
Identifying the location in the downhole wireless communications network where the error is occurring
506
Lower a communications device, such as a hydrophone, into the wellbore to the location of the error
508
Optionally, determine the type of error occurring
If a power failure
510
If a mechanical failure
514
If a programming/software failure
518
512
Optionally, use downhole tool to wirelessly recharge battery in malfunctioning node
516
Use communications device to bridge gap where error is occurring, and transmit data signals from the lower (farther from the surface) communications node to the communication device and then from the communications device to the higher (closer to the surface) communication node or topside
520
Optionally, use downhole tool to wirelessly transmit new program/software to malfunctioning node
522
Produce hydrocarbons

FIG. 5


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