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(54) DISTRIBUTED ENVIRONMENTAL CONTROL IN A WIRELESS SENSOR SYSTEM

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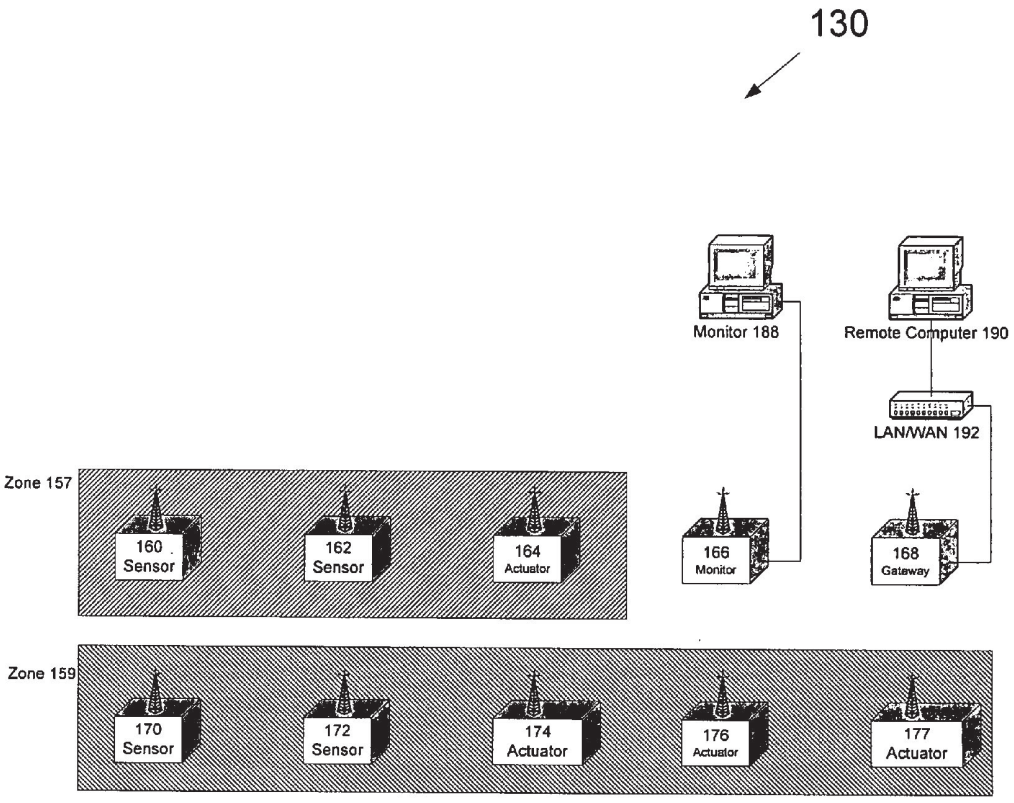
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(57) ABSTRACT

A method for providing environmental monitoring and control includes providing a network of wireless nodes, the wireless nodes includes an array of sensor nodes and an array of actuator nodes, each wireless node including a wireless transceiver, a processor and one of a sensor device or an actuator device. The method further includes sending a message from a first wireless node to a second wireless node through wireless communication; and processing the message at the second wireless node. In operation, the message may include sensor data or a control command operative to control the sensor device or the actuator device in the second wireless node. In one embodiment, a sensor node processes sensor data and generate a control command as a message to be transmitted to an actuator node. In another embodiment, the actuator node transmits a message to a sensor node to request sensor data or control commands.



ecobee Exhibit 1005
ecobee v. Ollnova

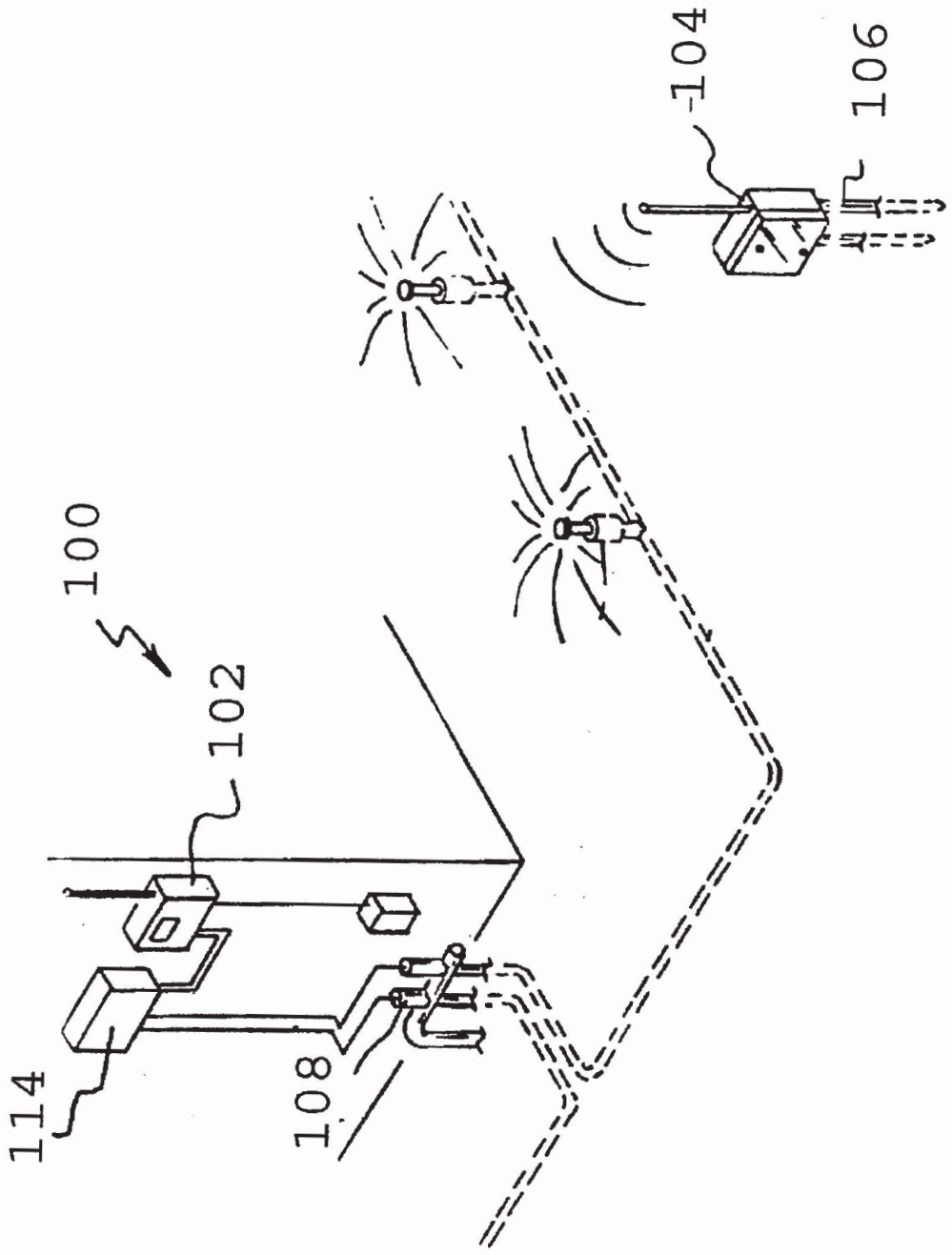


FIGURE 1 - PRIOR ART

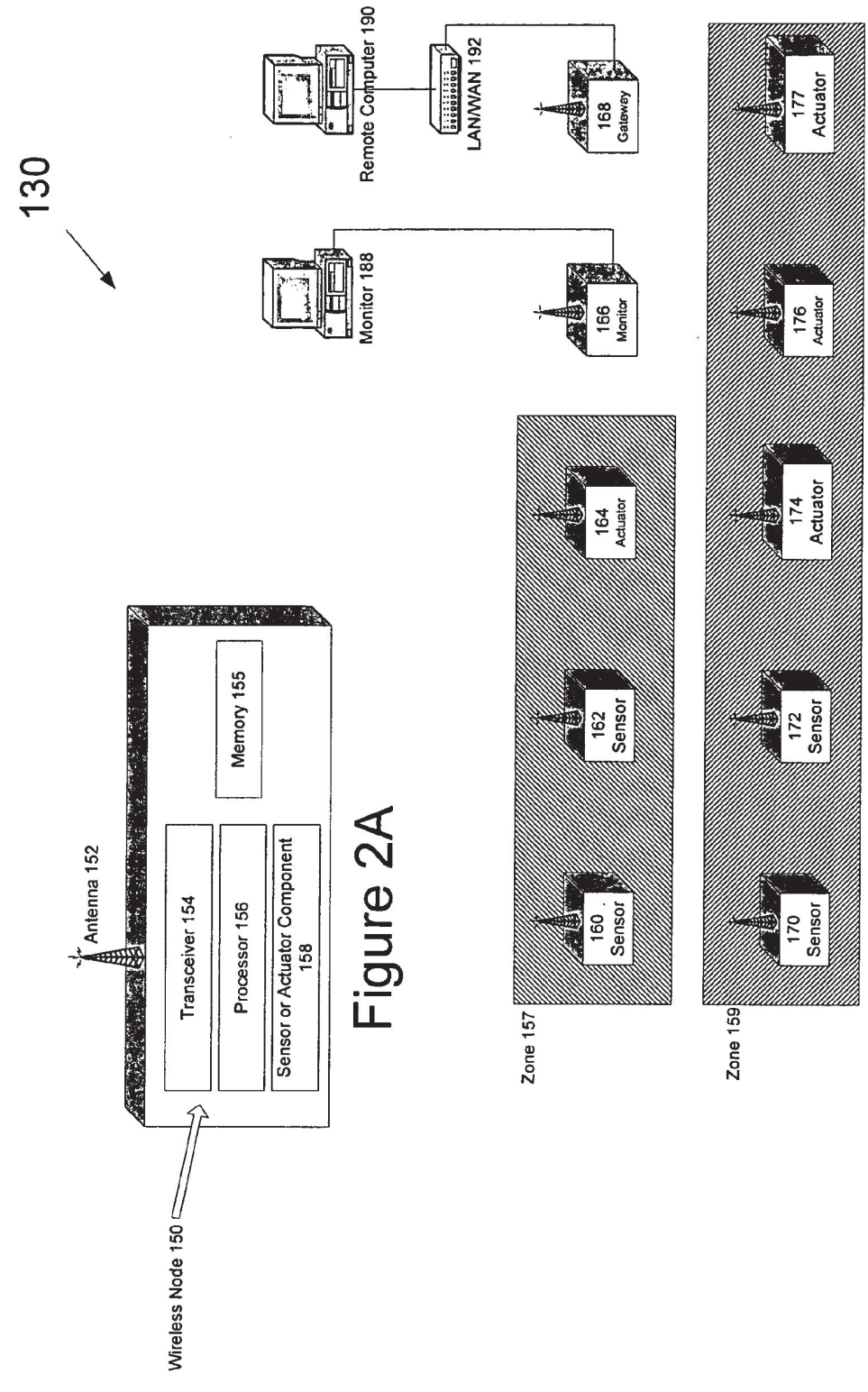


Figure 2A

Figure 2

Figure 3 - Message Routing

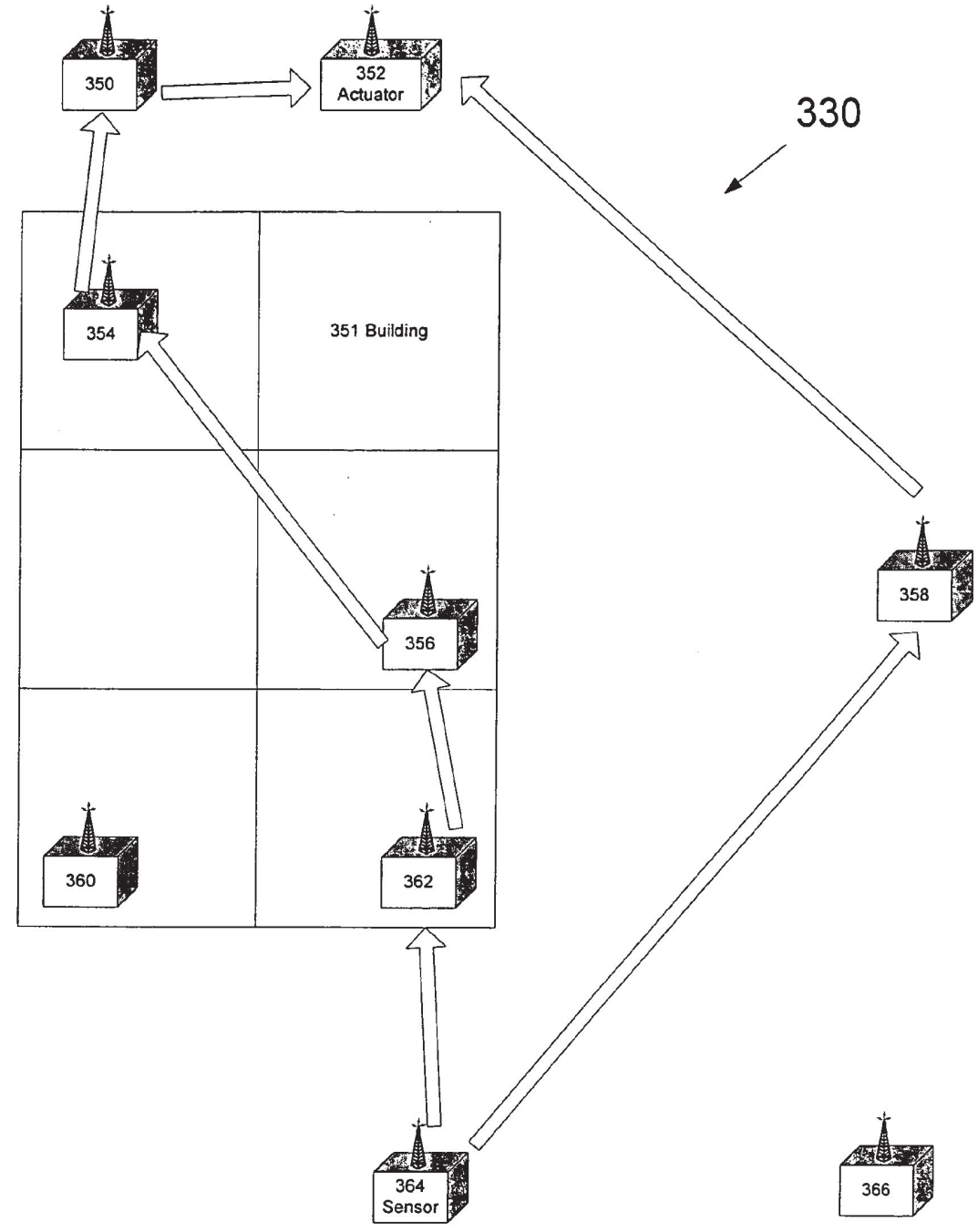


Figure 4 - Transceiver Routing

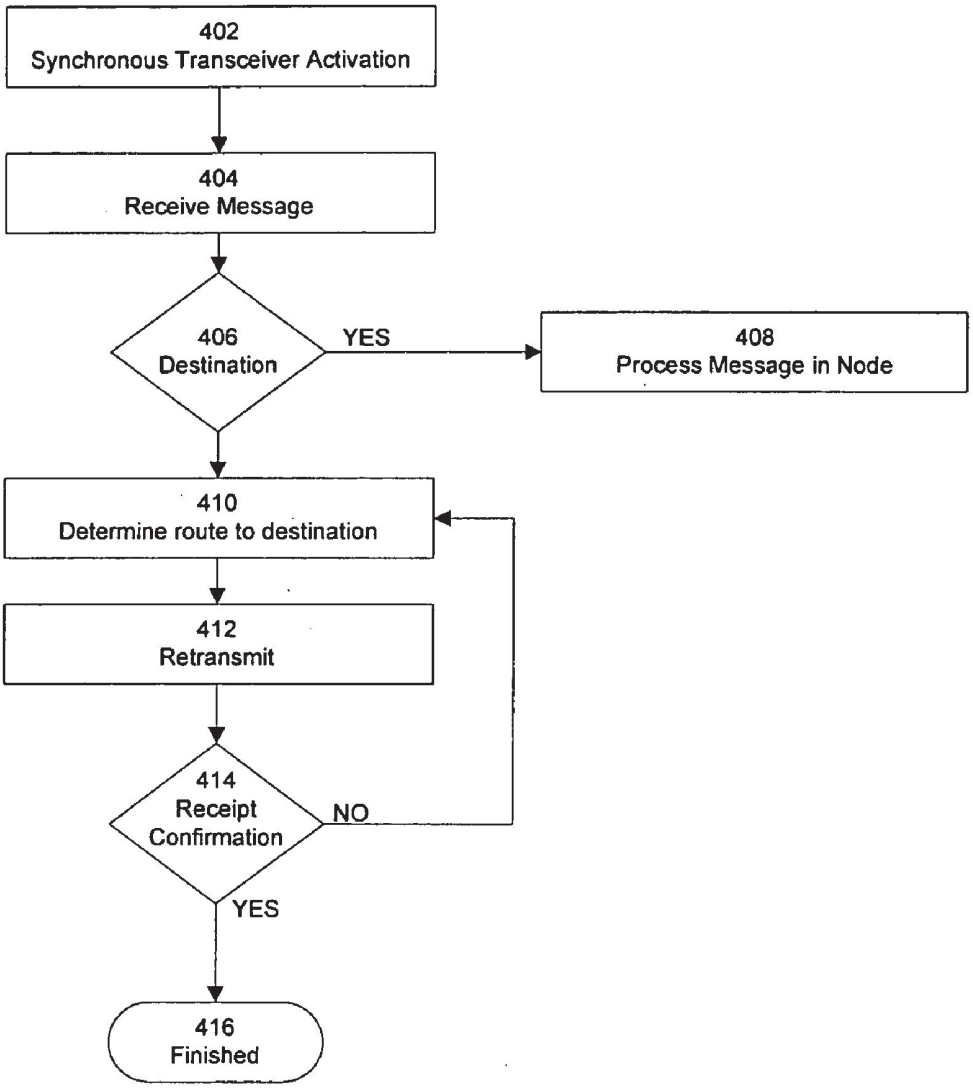


Figure 5 - Sensor Data Routing

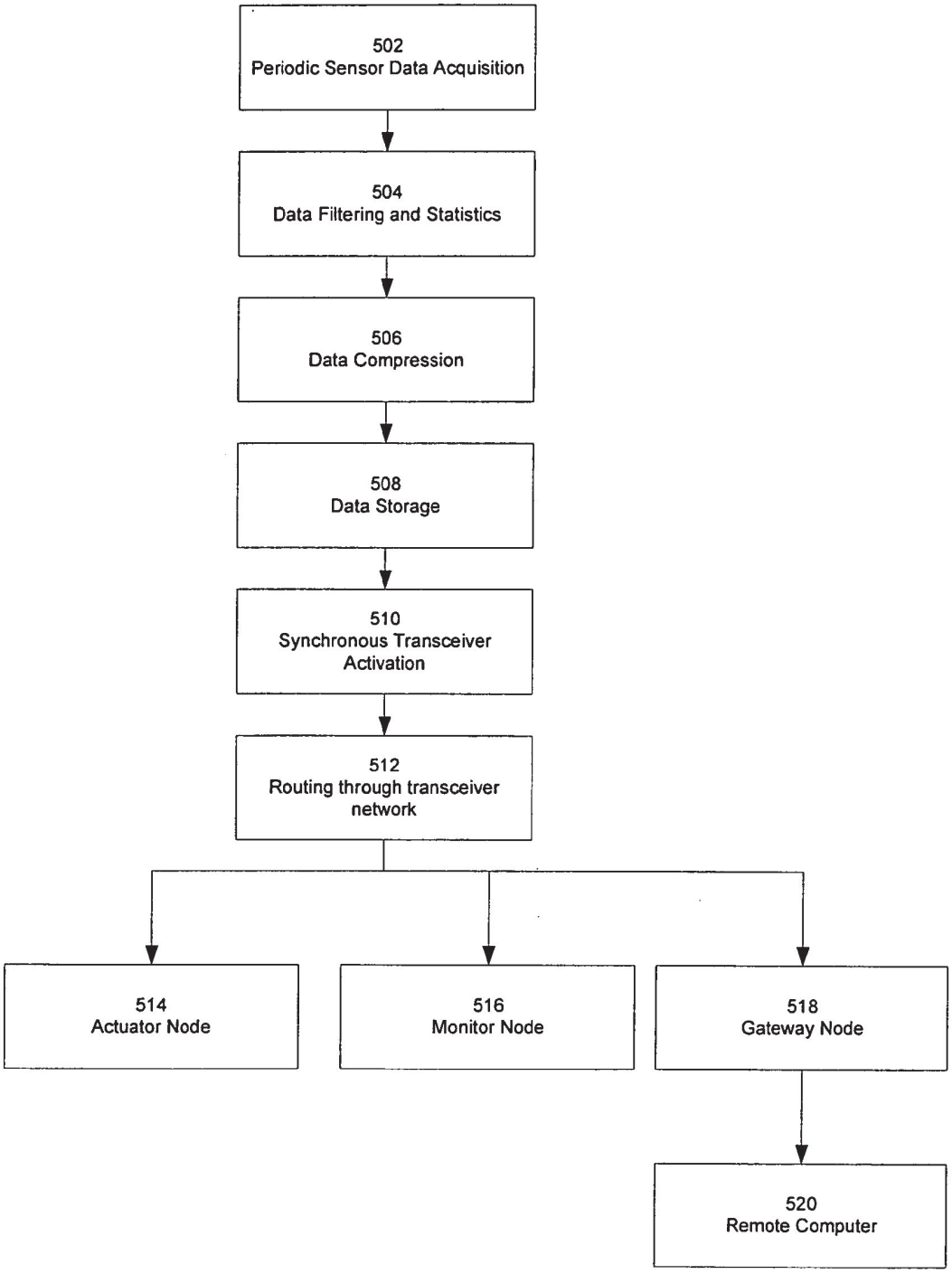


Figure 6 - Transceiver Synchronization

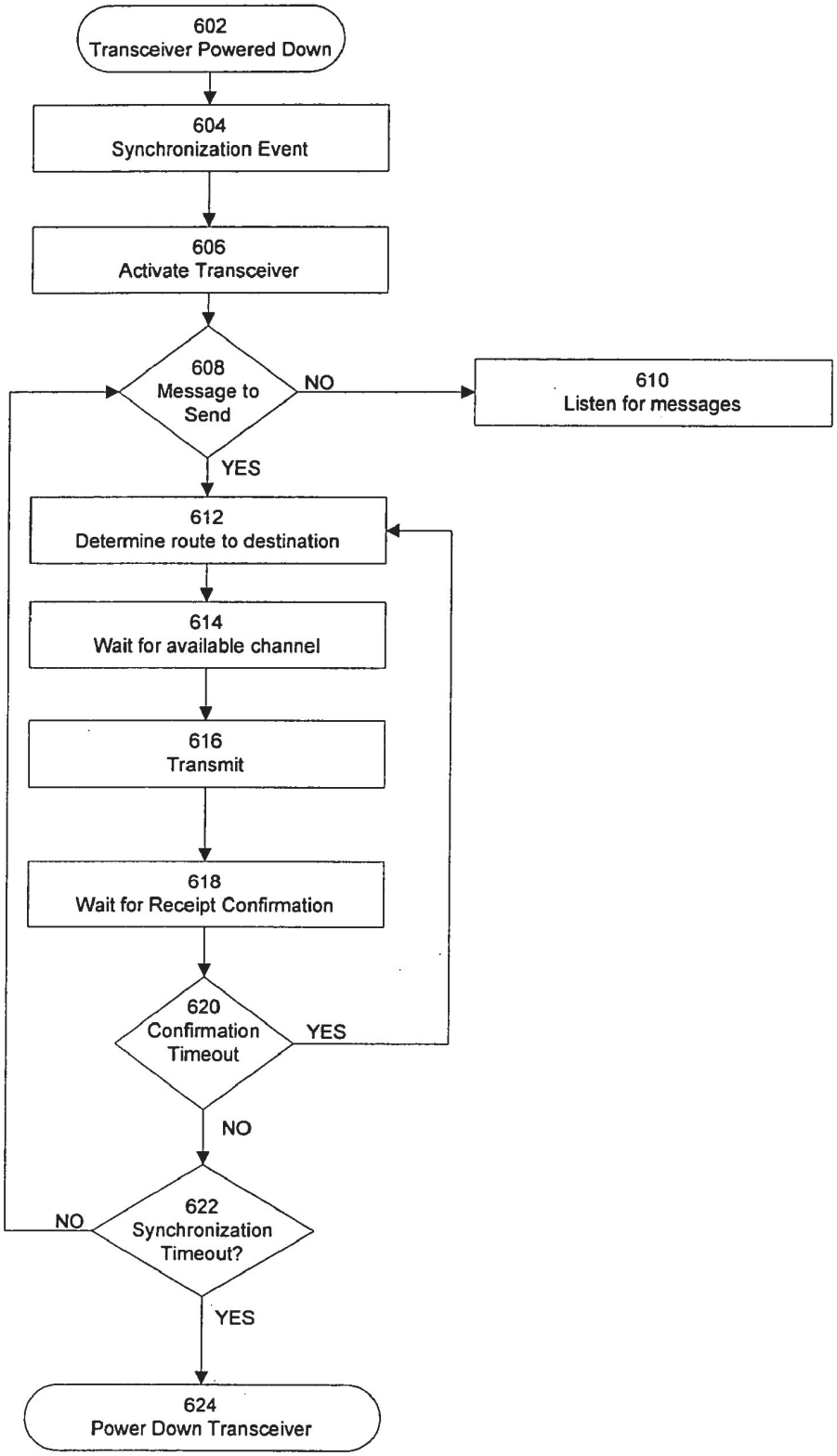


Figure 7 - Diagram of Soil Probe

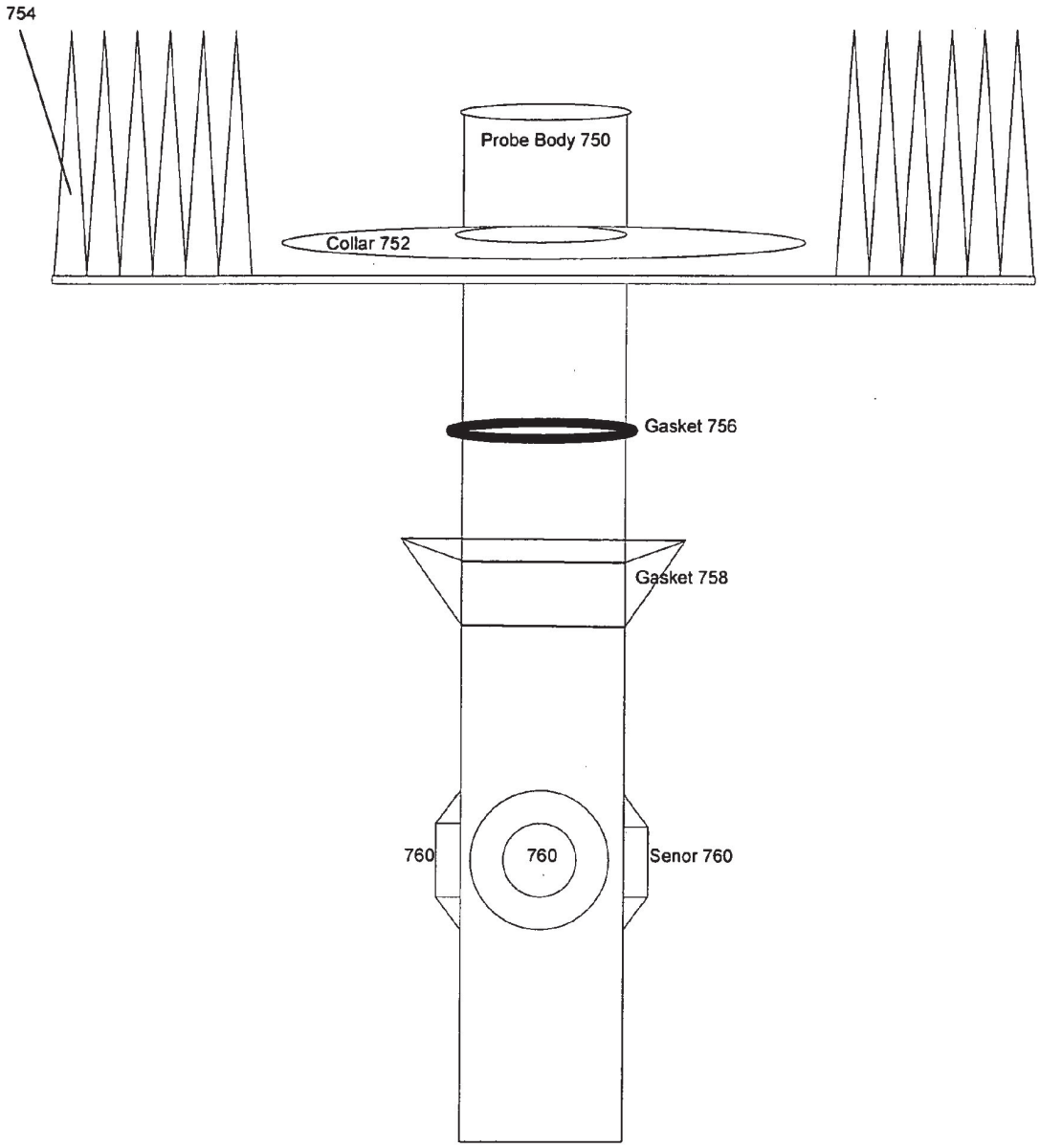


Figure 8 - Separable Probe Body

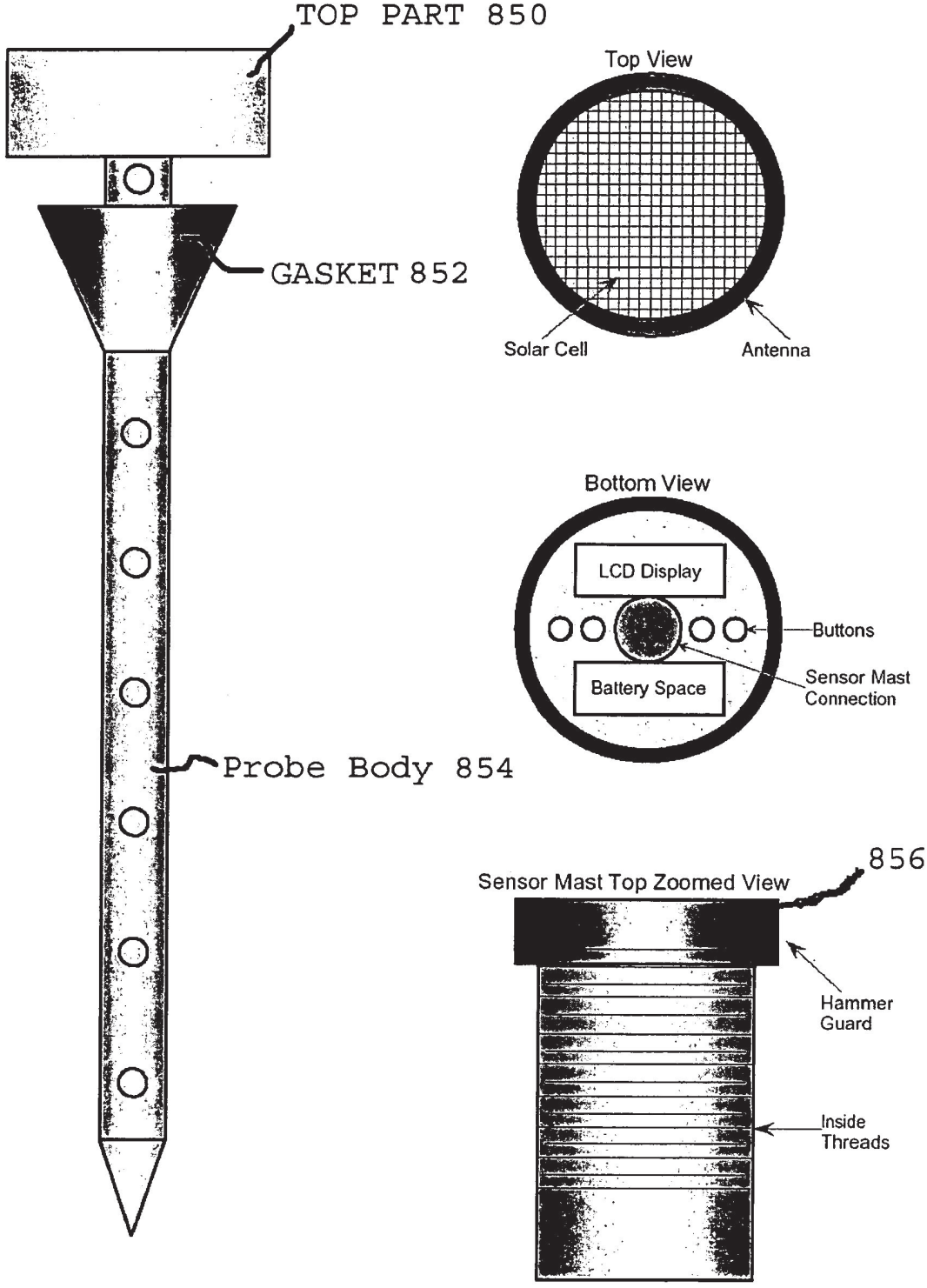


Figure 9

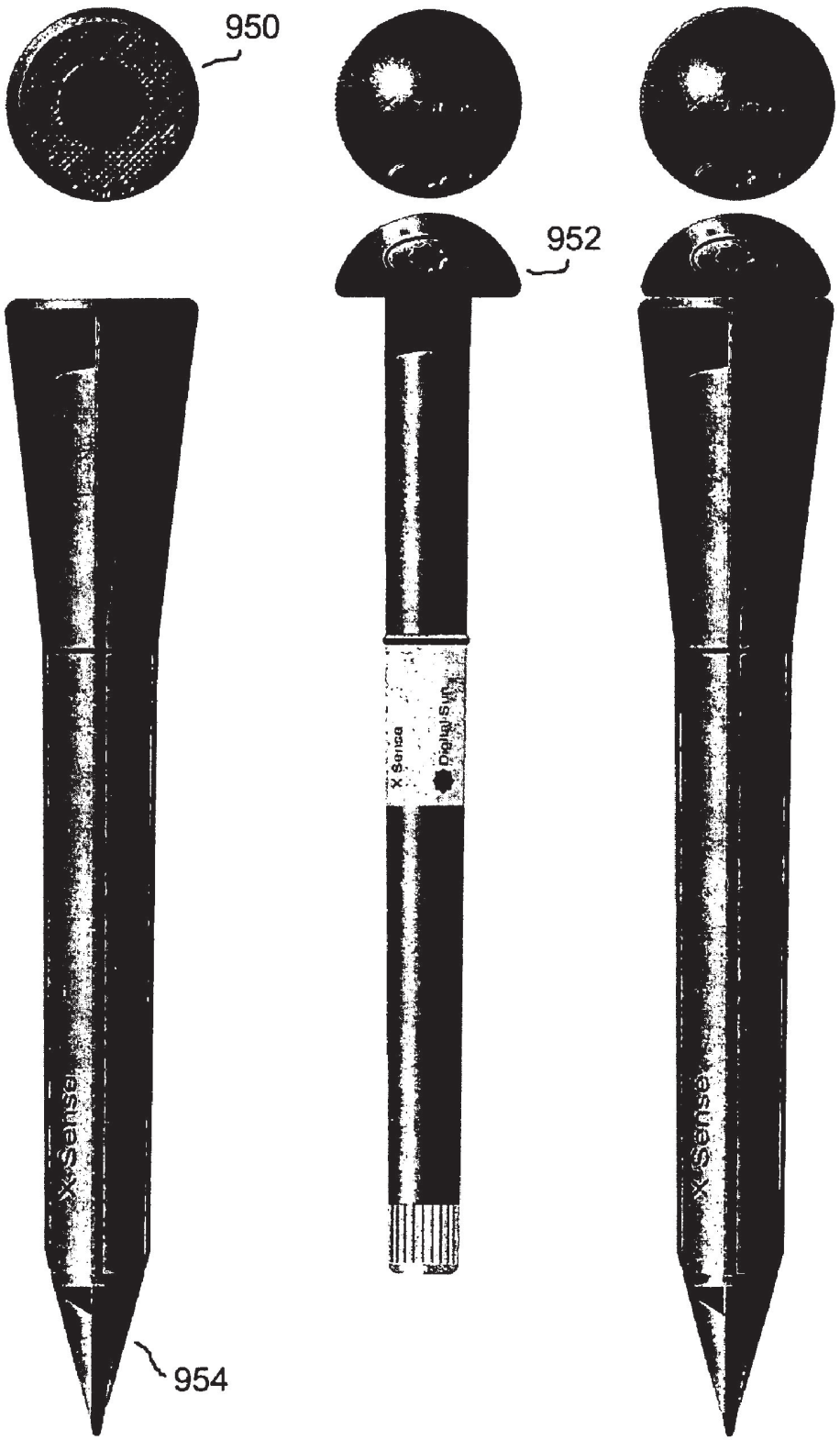
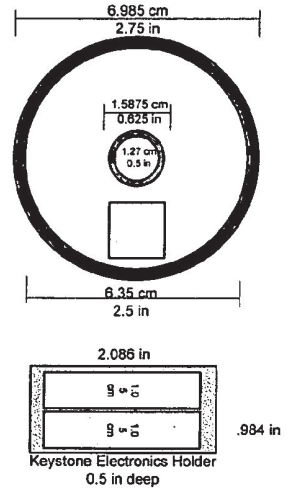


Figure 10 - Configuration and Dimensions of Probe Body



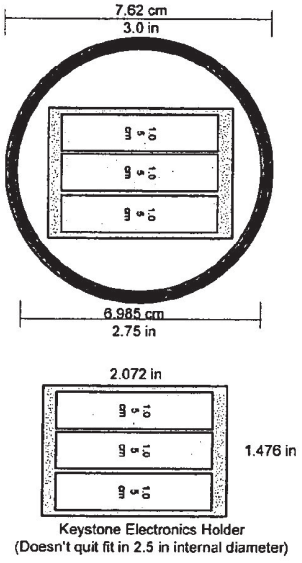


Figure 10A

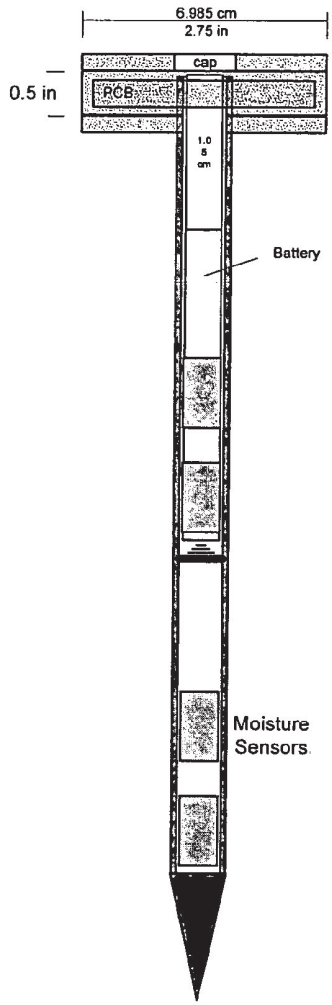
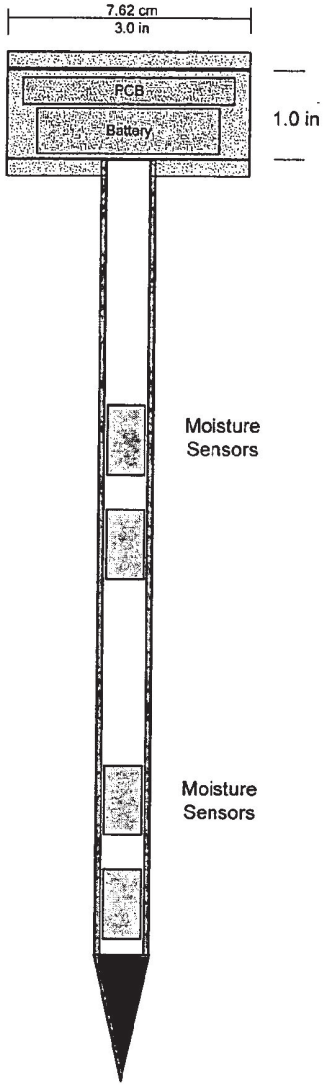


Figure 10B



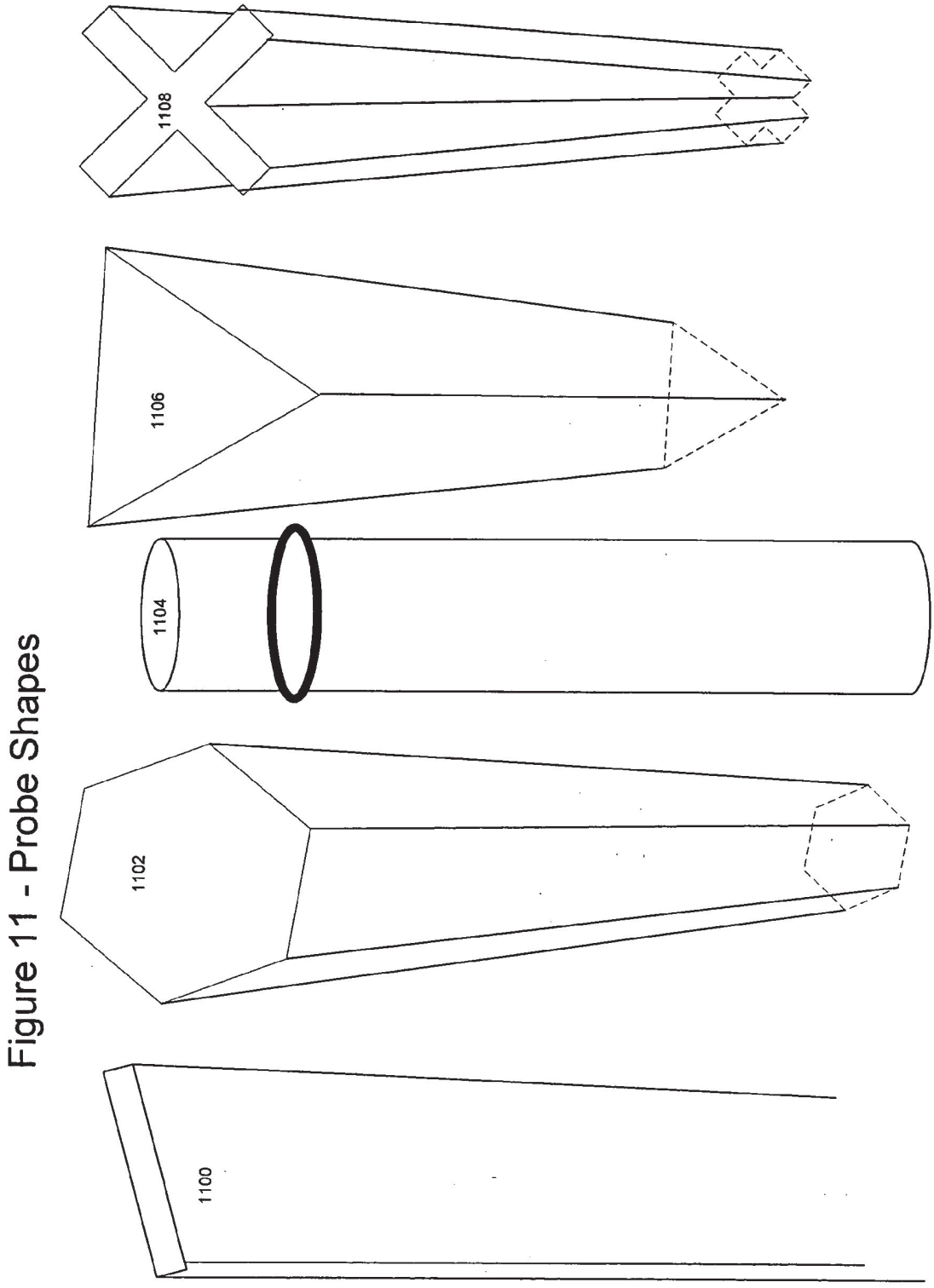


Figure 11 - Probe Shapes

Figure 12 - Occupancy Detection

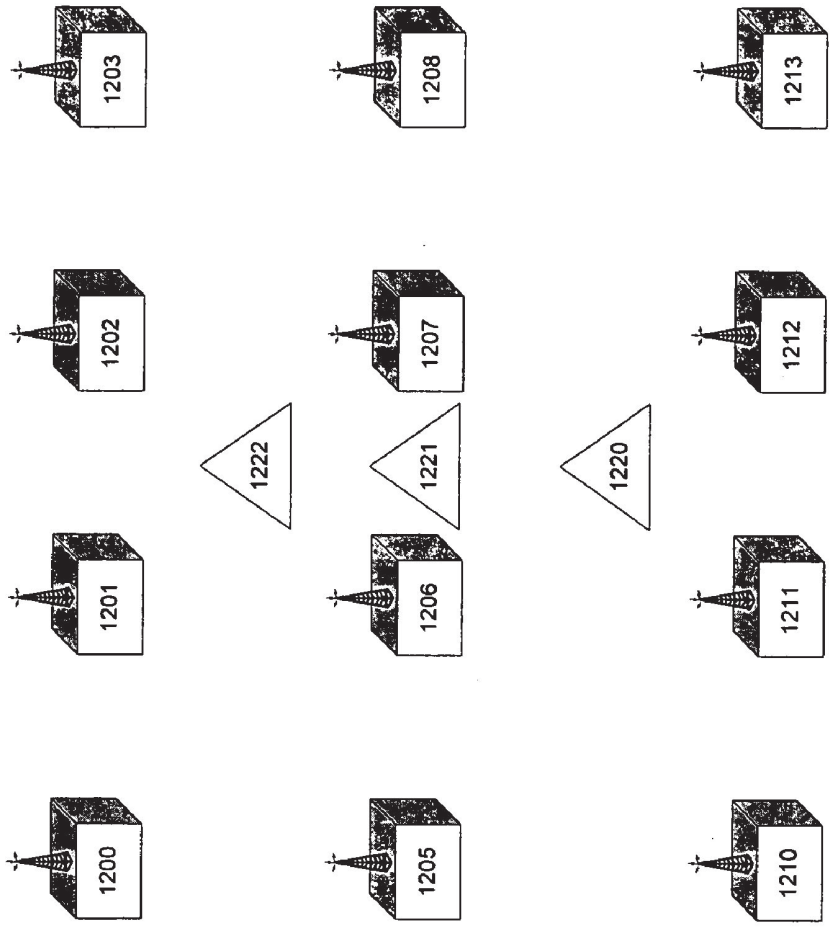


Figure 13 - Common Line Control

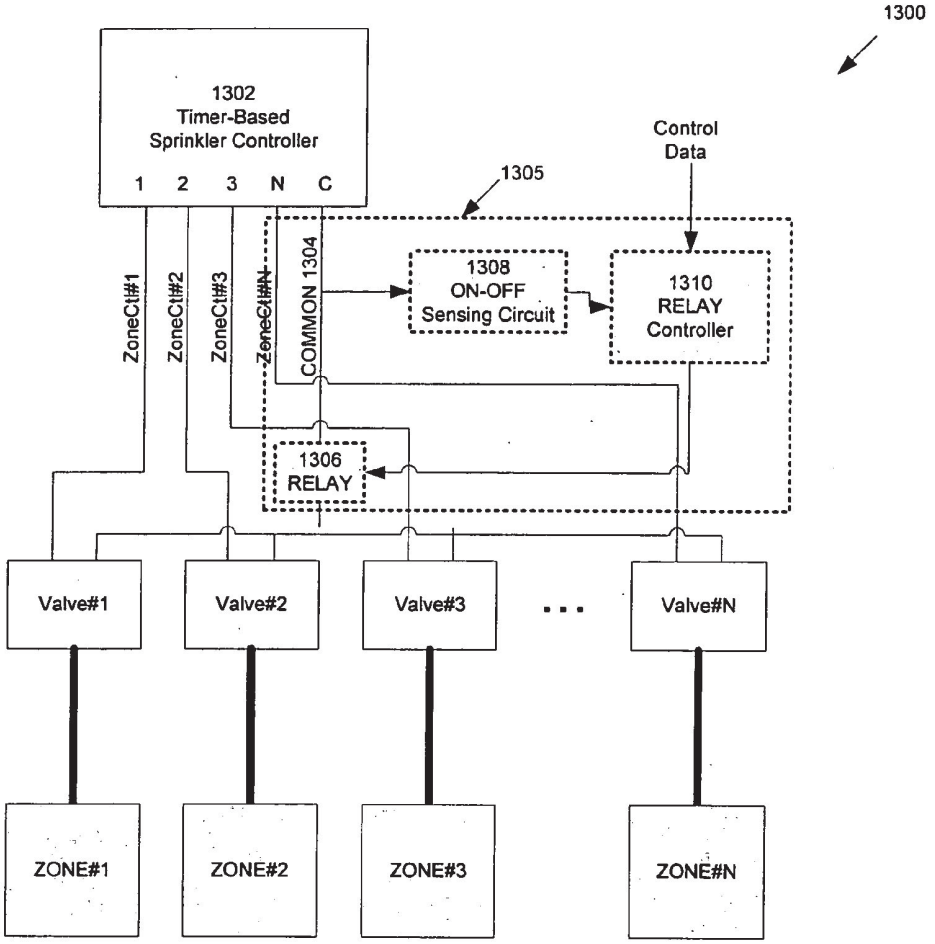
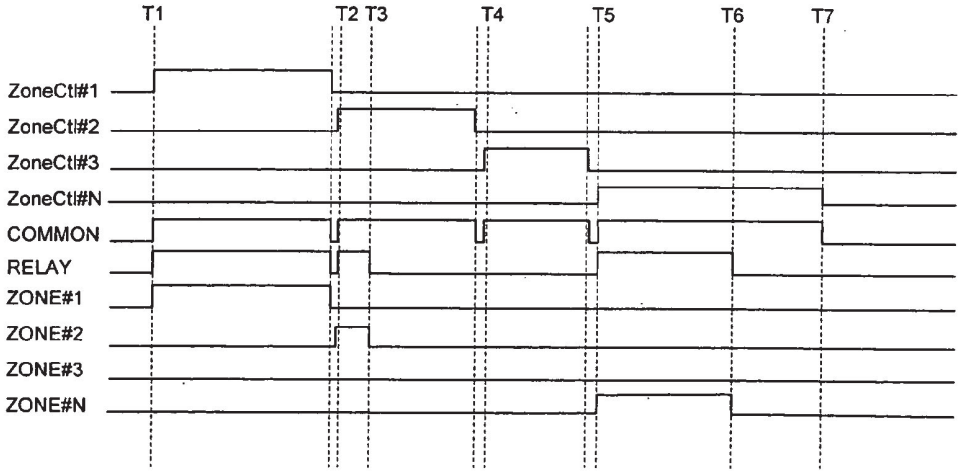


Figure 14



DISTRIBUTED ENVIRONMENTAL CONTROL IN A WIRELESS SENSOR SYSTEM

CROSS REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of U.S. Provisional Patent Application serial No. 60/421,963, filed Oct. 28, 2002, entitled "System for Environmental Monitoring and Control," of Dale K. Hitt, which application is incorporated herein by reference in its entirety.

[0002] This application is related to the following concurrently filed and commonly assigned U.S. patent applications: U.S. patent application Ser. No._____, entitled "Wireless Sensor System For Environmental Monitoring And Control," of Dale K. Hitt; U.S. patent application Ser. No. _____, entitled "Scheduled Transmission In A Wireless Sensor System," of Dale K. Hitt; U.S. patent application Ser. No. _____, entitled "Wireless Sensor Probe," of Dale K. Hitt et al.; U.S. patent application Ser. No., entitled "RF Based Positioning and Intrusion Detection Using A Wireless Sensor Network," of Dale K. Hitt; and U.S. patent application Ser. No. _____, entitled "Two-Wire Control of Sprinkler System," of Dale K. Hitt et al. The aforementioned patent applications are incorporated herein by reference in their entireties.

FIELD OF THE INVENTION

[0003] The invention relates to a wireless sensor system for environmental monitoring and/or control and, in particular, to systems and methods for an improved environmental monitoring and control system utilizing distributed wireless sensor platforms to provide continuous samples from multiple sensor types and multiple sensor positions and to establish multiple control points without the need for a centralized control.

DESCRIPTION OF THE RELATED ART

[0004] Control systems for automatic irrigation systems used for landscape and agricultural maintenance are known. Most common types of environmental monitoring and control for irrigation systems incorporate a means of controlling the start time and duration of watering cycles via a central timing controller. The need to adjust a watering cycle due to the environmental influence is necessary in order to save natural resources, reduce costs, and to improve the growing environment for plants. Such environmental conditions include temperature changes, relative humidity, precipitation, wind and cloud cover. In conventional control system, the primary means for halting an automatic watering cycle when certain environmental event occurs is by an operator manually suspending the cycle at the irrigation controller. In most situations this proves to be an ineffective means of conserving resources due to the inconsistent and inefficient methods followed by the operator. In fact, quite often the operator ignores the need to suspend the watering cycle altogether, and in some cases neglects to resume the watering cycle when required, leading to both over-watered and under-watered landscaping.

[0005] It is because of this unreliable and inconvenient manual method that environmental sensors were developed that allow for an automatic interruption of the controller due to an environmental condition. The use of sensors for irrigation systems has proven to be an effective and economical method of conserving water, energy, and money.

[0006] One of the major drawbacks of the conventional environmental sensors is the extensive installation time and difficult methods required for a proper installation. A soil moisture sensor is usually installed in the ground by boring of an precisely sized hole, placing the sensor at the appropriate depth to measure the soil properties in the root zone, placing a slurry of water and soil in the hole to assure that the sensor has good contact with the soil and try to restore the soil in the hole to its' previous condition as much as possible so that the sensor provides readings that correctly reflect the state of the soil. If the soil is not restored properly, water and fertilizer can drain down along the hole to the sensor and corrupt the sensor readings.

[0007] It is common for soil to be stratified into regions of varying textures, composition and drainage properties. Digging a hole and refilling it with slurry disrupts these strata around the sensor and decreases the accuracy of the sensor readings.

[0008] As the soil cycles from wet to dry, it is possible to shrink back from the senor and loose contact. If this happens, the sensor can no longer read the soil status properly. Sometimes, rewetting the soil is not sufficient to restore the sensor contact and the sensor must be reinstalled.

[0009] The wires that run from the sensors up through the soil to the surface are then routed either to a central controller directly or to a central controller through a wireless transmission system. This method is burdensome in time, tools required and is prone to unsuccessful installation through poor seating of the sensor in the soil, poor representation of the target soil by the sensed soil that was disturbed by installation, and electrical noise in connecting wires. The central controller receives the signals from the remote sensors and determines whether or not to start the next irrigation cycle for a particular irrigation zone.

[0010] By way of example, conventional sensors and sensor controlled irrigation systems are described in U.S. Pat. No. 5,424,649 to Gluck et al.; U.S. Pat. No. 5,351,437 to Lishman; U.S. Pat. No. 4,937,732 to Brandisini; U.S. Pat. No. 5,083,886 to Whitman; U.S. Pat. No. 4,524,913 to Bron; and U.S. Pat. No. 4,971,248 to Marino; and U.S. Pat. No. 5,813,606 to Ziff. **FIG. 1** duplicates FIG. 1 of the Ziff patent and illustrate a radio controlled sprinkler control system where a transmitter including a moisture sensor communicates with a receiver controlling the actuation of the sprinklers. The sprinklers are actuated by a signal generated by the moisture sensor disposed to measure the moisture level of the ground.

[0011] The cultivation of agricultural crops has evolved over the years as the size and scale of farms has increased from small family farms to large-scale farms. Irrespective of a farm's size, variations in terrain, soil conditions and weather exposure produce non-uniformities of field conditions which affect the preparation and growing of crops. In order to optimize crop yields, farmers have historically kept track of rainfall, humidity and temperature, as well as soil conditions and the occurrence of pest infestations. Soil has been analyzed to determine nitrogen levels and various other conditions. Furthermore, advances have been made with the introduction of field condition sensing and data collection

that enable gross categorization of agronomic information on a field. However, further improvements are needed that will enable better collection and management of information so that yields can be increased, without increasing the costs of production.

[0012] Recently, in-ground moisture sensors have been combined with an irrigation controller to control an irrigation cycle of an area of soil. More particularly, such irrigation controllers have been used to control stationary irrigation devices such as those used in golf courses and in orchards. However, such systems were limited in that in-ground sensors have required costly long range wireless communications systems to send data back to a central monitoring and control unit. Therefore, it is cost prohibitive to provide a large number of sensors in order to cover a large agricultural field being processed by a large-scale irrigation device such as a center-pivot irrigation device. Furthermore, such stationary irrigation systems are not suitable for irrigating large-scale agricultural fields due to the large number of sprinklers needed on the irrigation system. Furthermore, an agricultural field needs to be periodically cultivated and a complex in-ground irrigation system will cause problems when the field is being turned over and prepared for its next cultivation cycle.

[0013] Other areas of recent improvement in the field of agriculture involve the use of precision agriculture products. Precision agriculture products typically utilize variable-rate application devices, global positioning system (GPS) devices, and geographic information systems (GIS). Satellite-based global positioning systems enable the determination of precise locations within a field of interest. Geographic information systems enable data management of detected conditions on a field of interest.

[0014] One presently available representative differential global positioning system is manufactured by Trimble, and is sold under the product name Direct GPS for Arc View, Trimble Surveying and Mapping Division, 645 North Mary Avenue, P.O. Box 3642, Sunnyvale, Calif. 94088-3642.

[0015] One representative geographic information system (GIS) is presently available from Environmental System Research Institute, Inc. (ESRI), 380 New York Street, Redlands, Calif. 92373-8100, under the name "ARCVIEW.RTM for Agriculture." Such a GIS system enables the management of agricultural information by way of a graphical user interface. The GIS system consists of software implemented on a computer, and forms a graphical display that easily enables a user to tabulate data and evaluate collected data for making decisions about a crop being cultivated.

[0016] Far-distance data collection techniques have been used for determining certain agronomic features on a field being studied. Satellites imaging techniques and aerial photography techniques have enabled the collection of vast arrays of data in order to characterize agronomic information on large fields of interest. For example, thermal imaging cameras have been used to determine thermal characteristics of a field being observed. However, such cameras produce an array of pixels having limited resolution, and further, the cameras can only collect information periodically when weather conditions permit flight overhead. The presence of certain crop and soil conditions can manifest themselves in the form of a thermally detectable variation upon the land. Detection can also be performed in the visible, infrared and ultraviolet ranges, enabling the determination of correlated features with such information.

[0017] However, the ability to collect agronomic information on a field of interest via far-distance imaging techniques often has limited capabilities. For example, inclement weather conditions can block the ability to detect agronomic features. For cases of satellites, the presence of cloud cover can disrupt detection of such information. During certain periods of a growing cycle for a crop, the timing of such information can be critical to successful harvesting. The data from these techniques is not available continuously, therefore is inappropriate for providing real-time feedback for control of irrigation systems. Hence, an improved technique that enables the continuous detection of such agronomic information during any time of day, and under any type of weather condition, is desired. Furthermore, a sensing device that enables the detection of an increased number of different agronomic features is also desired. Even Furthermore, sensing devices that enable closed-loop control of irrigation is required.

[0018] Although precision agriculture products have recently enhanced the ability to increase crop yields, further improvements are needed to reduce the overall cost and usability of such systems while improving the effectiveness. For example, improvements are needed to sensor based, closed-loop control of such systems to better control the application of water and/or chemicals to a field based upon the real-time detection of needs. Furthermore, improvements are needed to the sensing systems in order to reduce their overall cost, while enhancing their effectiveness.

[0019] There are a variety of systems for monitoring and/or controlling any of a number of systems and/or processes, such as, for example, manufacturing processes, irrigation systems, personal security systems, and residential systems to name a few. In many of these systems, a central host computer in communication with a wide area network monitors and/or controls a plurality of remote devices arranged within a geographical region. The plurality of remote devices typically uses remote sensors to monitor and actuators to respond to various system parameters to reach desired results. A number of automated monitoring systems use computers or dedicated microprocessors in association with appropriate software to process system inputs, model system responses, and control actuators to implement corrections within a system. In control systems, the dependence on a central controller reduces the reliability of the system because a failure in this controller brings down the system.

[0020] Various schemes have been proposed to facilitate communication between the host computer and the remote devices within the system, including RF transmission, and control signal modulation over the local power distribution network. For example, U.S. Pat. No. 4,697,166 describes a power-line carrier backbone for inter-element communications. As recognized in U.S. Pat. No. 5,471,190, there is a growing interest in home automation systems and products that facilitate such systems. Recognizing that consumers will soon demand interoperability between household systems, appliances, and computers, the Electronics Industry Association (EIA) has adopted a standard, known as the Consumer Electronics Bus (CEBus). The CEBus is designed to provide reliable communications between residential devices.

[0021] One problem with the use of control systems technology to distributed systems is the cost associated with developing the local communications infrastructure necessary to interconnect the various devices. A typical approach to implementing control system is to install a local network of hard-wired sensors and actuators along with a local controller. Not only is there expense associated with developing and installing appropriate sensors and actuators, but the expense of connecting functional sensors and actuators with the local controller is often prohibitive. Another prohibitive cost is the expense associated with the expense associated with programming the local controller.

[0022] Accordingly, an alternative solution for implementing a distributed control system suitable for monitoring and controlling remote devices that overcomes the shortcomings of the prior art is desired.

[0023] U.S. Pat. No. 5,905,442 discloses a wireless automation system with a centralized remote control that controls I/O devices for providing electrical power to appliances from power outlets of the power mains in building. The remote control and I/O devices comprise RF transceivers, and the system includes dedicated repeater units for repeating signals to I/O devices out of the range of the remote control.

[0024] U.S. Pat. No. 5,875,179 describes a method for synchronizing communications over a backbone architecture in a wireless network. The system invokes two controllers, one of which is a master and another which is an alternate master which will be activated only when the master is out of work. Dedicated repeaters and I/O devices in the system are commonly designated as nodes. There are generally functional difference between repeater nodes and end (I/O) nodes.

[0025] U.S. Pat. No. 4,427,968 discloses a wireless automation system with flexible message routing. A central station produces a signal for a I/O device; the signal contains a route code, an address code, an identifying code and a message code. Dedicated repeaters in the architecture receive the signals and follow a specified procedure for repeating signal. Repeaters may also be addressed as end nodes, e.g. in order for the controller to download routing tables.

[0026] U.S. Pat. No. 4,250,489 describes a communication system having dedicated repeaters organized in a pyramidal configuration. The repeaters are bidirectionally addressable and may receive interrogation signals telling a repeater that it is the last repeater in the chain. The repeaters are not connected to appliances and do not perform any functions besides repeating and routing signals.

SUMMARY OF THE INVENTION

[0027] According to one embodiment of the present invention, a method for providing environmental monitoring and control includes providing a network of wireless nodes, the wireless nodes includes an array of sensor nodes and an array of actuator nodes, each wireless node including a wireless transceiver, a processor and one of a sensor device or an actuator device. The method further includes sending a message from a first wireless node to a second wireless node through wireless communication; and processing the message at the second wireless node. In operation, the message may include sensor data or a control command operative to control the sensor device or the actuator device in the second wireless node. In one embodiment, a sensor node processes sensor data and generate a control command as a message to be transmitted to an actuator node. In another embodiment, the actuator node transmits a message to a sensor node to request sensor data or control commands.

[0028] The present invention is better understood upon consideration of the detailed description below and the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0029] **FIG. 1** is a radio controlled sprinkler control system as described in U.S. Pat. No. 5,813,606.

[0030] **FIG. 2**, including insert **FIG. 2**A, is a schematic diagram of a wireless environmental monitoring and control system according to one embodiment of the present invention.

[0031] **FIG. 3** is a block diagram illustrating the operation of a wireless environmental monitoring and control system according to one embodiment of the present invention.

[0032] **FIG. 4** is a flow chart illustrating the operation of each wireless node for receiving and transmitting messages within the environmental monitoring and control system according to one embodiment of the present invention.

[0033] **FIG. 5** is a flow chart illustrating the sensor data processing and routing operation according to one embodiment of the present invention.

[0034] **FIG. 6** is a flow chart illustrating the transceiver synchronization operation according to one embodiment of the present invention.

[0035] **FIG. 7** is a cross-sectional diagram illustrating a sensor node according to one embodiment of the present invention and the installation of the sensor node in the ground.

[0036] **FIGS. 8 and 9** are two embodiments of a sensor node of the present invention constructed using separable probe body.

[0037] **FIGS. 10A and 10B** illustrate differential embodiments of the sensor nodes of the present invention.

[0038] **FIG. 11** illustrates variations on the probe body configuration.

[0039] **FIG. 12** is a schematic diagram illustrating the use of the environmental monitoring and control system of the present invention for occupancy detection.

[0040] **FIG. 13** is a block diagram of an automatic sprinkler system **1300** incorporating the two-wire control system according to one embodiment of the present invention.

[0041] **FIG. 14** is a timing diagram illustrating the operation of the sprinkler system of **FIG. 13** according to one embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0042] In accordance with the principles of the present invention, a wireless environmental monitoring and control system utilizes an array of wireless sensors for providing

extended range and multiple control points within the array. The wireless environmental monitoring and control system can support sensing and irrigation control over a large area without the need for a central controller. By providing distributed monitoring and control, the control system of the present invention can be used to realize more efficient water utilization and improved crop yield.

A. Multi-hop Wireless Sensor Irrigation Control System

[0043] **FIG. 2** is a schematic diagram of a wireless environmental monitoring and control system according to one embodiment of the present invention. In general, wireless environmental monitoring and control system **130** (system **130**) is configured to include one or more irrigation zones where each irrigation zone can include one or more sensor nodes and one or more actuator nodes. System **130** can also include other nodes providing other supporting functions as will be described in more detail below. The sensor nodes, actuator nodes and other nodes in system **130** form a wireless communication network in which messages, such as sensor data, operating data, and commands, are communicated wirelessly between the nodes.

[0044] In **FIG. 2**, wireless environmental monitoring and control system **130** (system **130**) is illustrated with irrigation zones **157** and **159**. In the present embodiment, irrigation zone **157** is supported by sensor nodes **160** and **162** and an actuator node **164**. Actuator node **164** controls one or more irrigation valves for providing irrigation within zone **157**. Sensor nodes **160** and **162** can represent different types of sensors for providing sensor data or commands to actuator **164** to control the irrigation of zone **157**. Actuator **164** is thus disposed to receive sensor data or commands from one or more sensor nodes. Irrigation zone **159** is supported by sensor nodes **170** and **172**, actuator nodes **174** and **176** and a repeater node **177**. Actuator nodes **174** and **176** each control one or more irrigation valves for providing irrigation within zone **159**. Similar to zone **157**, sensor nodes **170** and **172** can represent different type of sensors and can transmit sensor data or commands to multiple actuator nodes **174** and **176**. Each of actuator nodes **174** and **176** can receive sensor data or commands from one or more sensor nodes.

[0045] Wireless environmental monitoring and control system **130** can also include other nodes for providing other supporting functions. Referring to **FIG. 2**, the sensor and actuator nodes within system **130** also communicate with nodes with monitoring capabilities only. For example, a local monitor node **166** is provided for communication with any one of the sensor and actuator nodes. Local monitor node **166** can be coupled to a personal computer **188** for receiving, storing and/or processing data received from the sensor nodes or actuator nodes. A gateway node **168** can also be provided to facilitate access to a local area network or the internet. In the present embodiment, gateway node **168** is connected through a local area network to a computer **190** which provides access to the Internet or an intranet. In this manner, monitoring and/or control of system **130** can be facilitated remotely through a local area network through the Internet. A repeater node **177** is also provided. Repeater node **177** does not provide other functions and act only to relay messages between the nodes in system **130**. In one embodiment, a sensor node or an actuator node can also act as a repeater node for relaying messages between other nodes. System **130** can also include a user interface node (not shown) whereby a user can access the network of sensor and actuator nodes for reading data and for providing control.

[0046] In system **130**, each sensor node and each actuator node incorporates a wireless communication transceiver to enable wireless communication between the nodes. An insert **FIG. 2A** in **FIG. 2** is a block diagram of a sensor/actuator node according to one embodiment of the present invention. In the present description, a sensor node, an actuator node or other nodes in the system will be collectively referred to as "a wireless node" in the environmental monitoring and control system of the present invention. In **FIG. 2A, a** wireless node **150** includes an antenna **152**, a wireless transceiver **154**, a processor **156** and a node component **158**. The wireless transceiver of each wireless node may communicate with a memory **155** that stores a unique transceiver identifier that identifies the wireless network. Depending on the function of the wireless node, the node component may further include sensor or actuator components. For example, if wireless node **150** is a sensor node, node component **158** will be implemented as a sensor component, such as a soil moisture sensor or an temperature sensor. If wireless node **150** is an actuator node, node component **158** will be implemented as an actuator component for providing the drive voltage to drive one or more irrigation valves.

[0047] Each wireless node in system **130** can be powered by a power source, such as by solar power or by battery power. In one embodiment, the wireless node is powered by a rechargeable battery. The rechargeable battery may be recharged periodically via a solar panel. In one embodiment, the transceiver circuit is independently powered so that when the wireless node is acting merely as a repeater for relaying transmissions to other wireless, the transceiver does not drain power away from the sensor or the actuator component. In one embodiment, the battery power level or the solar power level at each wireless node is measured and monitored so that power failures at any node can be detected.

[0048] Processor **156** controls the operation of the wireless transceiver and the node component. Processor **156** usually includes a data interface configured to receive and/or transmit signals to node component **158**. If the signal output from the sensors/actuator components is an analog signal, the data interface may include an analog-to-digital converter (not shown) to digitize the signals. For example, processor **156** can be operated to receive incoming control data from transceiver **154** and use the control data to control the actuator component. Processor **156** can also be operated to receive sensor data from a sensor component and direct the sensor data to be transmitted to an actuator node through the transceiver. Processor **156** can also be provided with programming data to derive control data for an actuator node based on the sensor data received.

[0049] In accordance with the present invention, the wireless node can be built using different degrees of the integration. In one embodiment, the transceiver circuit, the processor and the memory are integrated in the same housing as the sensor or actuator component. In another embodiment, the transceiver circuit may be installed in close

proximity to the processor and sensor/actuator components and communicate with the processor via a wired or a wireless connection.

[0050] In one embodiment, the sensor component can be any one of or a combination of: an air temperature sensor, a relative humidity sensor, a light level sensor, a soil moisture sensor, a soil temperature sensor, a soil dissolved oxygen sensor, a soil pH sensor, a soil conductivity sensor, a soil dielectric frequency response sensor. The actuator component can be any one of or a combination of: an actuator position control, an actuator flow rate control, a water flow control, a fertilizer flow control, and a lighting control.

[0051] In one embodiment, each of the wireless nodes in environmental monitoring and control system **130** is configured to transmit a low-power radio frequency (RF) signal. Thus, each wireless node requires limited power to operate. The transmitter power and range may be appropriately selected for the desired operating requirements. More specifically, in one embodiment, each sensor or actuator node operates as a repeater node for relaying control or sensor data to other nodes within the system, thereby effectively extending the range of each node, as will be described in more detail below.

[0052] In **FIG. 2**, the wireless nodes are depicted without a user interface. However, in other embodiments, the wireless nodes may be equipped with a user interface, including but not limited to pushbuttons, switches, an alphanumeric keypad, LED indicators, LCD display or any other type of user interface device suitably configured with software to accept operator input. Wireless nodes. that require user input, but do not have user interfaces can receive user input from nodes that do have user interfaces.

B. Distributed Environmental Control

[0053] In accordance with the present invention, the irrigation control actuator does not need to be controlled from a central controller. The actuator node can receive sensor data or commands directly over the system and determine the appropriate control response from the sensor data. The actuator node can coordinate with other actuator nodes in the network to sequence through irrigation cycles so that water pressure is maintained. As is well understood in the art, if too many sprinklers are on at once, water pressure can be reduced below necessary levels.

[0054] With an interconnected wireless network such as system **120** that provides processing capabilities at every node, nodes on the network can distribute signal processing, storage and analysis function to better optimize the use of the network resources. A distributed environmental control system for efficient and effective system management is thus realized. By providing a distributed control, the operation of wireless environmental monitoring and control system **130** can be flexible and various fail-safe can be realized.

[0055] In one embodiment, the sensor nodes collect sensor data and determine actuator function as needed. When actuator function is needed, messages can be sent across the wireless network from a sensor node to the respective actuator node. In another embodiment, any wireless node in the network can integrate data from one or more sensor nodes to determine the appropriate actuator function. Such a wireless node is sometimes referred to as "an intermediate node" where sensor data are sent for processing and resulting actuator commands are forwarded to the respective actuator nodes. The intermediate node functions as a data processing station supporting respective sensor nodes and respective actuator nodes.

[0056] In another embodiment, every wireless node in the network can receive data or commands from other wireless nodes, including user input nodes, actuator nodes, sensor nodes and other monitor nodes (like gateway nodes). Each wireless node integrates those data and/or commands to determine the correct operations. In one embodiment, sensor data from the sensor nodes are broadcast to all nodes in the network. Actuator nodes receiving the sensor data can selectively process the sensor data relevant to their function. For example, an actuator node in irrigation zone**1** receives data and processes the data from all sensor nodes related to the zone**1** only. The actuator node can also receive sensor data from weather sensor nodes and user input nodes and gateway nodes to have more information to make actuator decisions.

[0057] In system **130**, any of the wireless node, whether it is a sensor node or an actuator node, can transmit messages to any other node. Thus, a sensor node can process sensor data it is sensing and can issue commands to an actuator node for controlling the irrigation of a zone. Alternately, a sensor node can collect sensor data from itself and sensor data from other sensor nodes in the respective area and process the sensor data collectively. The sensor node can then provide commands accordingly to control the operation of the associated actuator node **164**.

[0058] In one embodiment, an actuator node sends a message to an associated sensor node requesting sensor data and/or commands. The sensor node in response processes the sensor data from itself or from associated sensor nodes and provide the sensor data and/or actuator commands to the requesting actuator node.

[0059] As described above, any wireless node in the network can function as a repeater node where messages are relayed or a data processing station where sensor data are processed and commands are generated. Thus, a wireless node wishing to transmit to another wireless node can utilize one or more intermediate repeater nodes for transmitting the message.

[0060] Referring to **FIG. 3**, sensor node **160** may communicate with at least one actuator node **164** either directly or via another wireless node, such as sensor node **162**. Similarly, sensor node **170** may communicate with at least one or more other sensor/actuator nodes, such as node **176**, on the network via wireless node **172**. Furthermore, one or more sensor/actuator nodes may be in direct communication with one or more monitor nodes **166** and **168**. In an alternate embodiment, the communication medium between the one or more sensor/actuator nodes may be wireless or, for relatively closely located configurations, a wired communication medium may be used.

[0061] One or more wireless nodes are configured and disposed to receive remote data transmissions from the various stand-alone wireless nodes. It is important to note that while a specific group of wireless nodes is assigned to a given zone, all of the wireless nodes within the environmental monitoring and control system can communication

with each other to relay messages to the desired node. For example, sensor node **160** in zone **157** can transmit a message to actuator node **164** through sensor node **172** in zone **159**, if that route is determined to be better suited for transmission. Similarly, sensor **170** in zone **159** can transmit sensor data to actuator node **176** through sensor node **162** and actuator node **164**, if that route is determine to be better suited for transmission.

[**0062**] Similarly, any of the wireless nodes in the system can communicate with the monitor node and the gateway node. Wireless gateway node **168** may be configured to convert the transmissions between TCP/IP format and wireless network format to provide communications between devices on the wireless network and remote device **190** via TCP/IP.

[**0063**] **FIG. 3** is a block diagram illustrating the operation of a wireless environmental monitoring and control system according to one embodiment of the present invention. In **FIG. 3**, wireless nodes **350-366** in environmental monitoring and control system **330** are geographically arranged such that the antenna patterns (not shown) associated with each wireless node overlap to create a coverage area. In this manner, environmental monitoring and control system **330** enables a wireless network node **364** (a sensor node) associated with the coverage area to communicate with another wireless node **352** (an actuator node) in the coverage area via several possible communication paths. For instance, wireless node **364** may communicate with wireless node **352** via several different communication paths, each path defined by one or more wireless nodes within the coverage area. For example, in **FIG. 3**, sensor node **364** may communicate with actuator node **352** via a wireless node **358** which can be a sensor node, an actuator node, or a monitoring node. Alternately, sensor node **364** may communicate with actuator node **352** through a series of intermediate nodes **362**, **356**, **354** and **350**. In this manner, the range of each wireless node can remain small to limit power consumption while ensuring a wide coverage area for system **300**.

[**0064**] **FIG. 4** is a flow chart illustrating the operation of each wireless node for receiving and transmitting messages within the environmental monitoring and control system according to one embodiment of the present invention. In the present embodiment, the transceivers in the wireless nodes of the system are synchronously activated to establish end-to-end network connectivity (step **402**). The wireless transceiver receives an incoming message via the antenna (step **404**). The transceiver receives the incoming message, modifies the received signal, and passes the modified signal onto the processor. The processor evaluates the message to determine the intended recipient (step **406**). If the intended recipient is the wireless node itself, the processor then prepares the appropriate response (step **408**). The response may include collecting data from the sensor or providing a control signal to the actuator. If the intended recipient is not the wireless node itself, the processor then prepares the message to be re-transmitted to the intended recipient. Specifically, the processor of the wireless node determines the best route to the destination (step **410**) and retransmits the message as necessary (step **412**). The best route can be determined by the smallest number of intermediate nodes, by nodes with the maximum power available and by most reliable links. The wireless node awaits confirmation of receipt of the message (step **414**). When the confirmation is not received, the wireless node attempts to retransmit the message by returning to step **410**. When confirmation is received, the processing for the message is completed.

[**0065**] The logic circuits for supporting the operation of each wireless node can be implemented in software or in firmware that is stored in a memory, such as memory **155**. The processor of the wireless node executes the instructions stored in the memory to carry out the message interpretation and transmission functions.

[**0066**] In one embodiment, the operation of environmental monitoring and control system for transmitting sensor data and control data can be implemented as follows. First, the transceiver in a wireless node may receive a command message on the antenna via a message protocol. The command message may be initiated from another wireless node, or any other device connected to the system through a gateway. The processor may evaluate the received message to determine if the recipient's address is its own unique address. If it is, then the processor evaluates the command and prepares a response message.

[**0067**] In response to the command message, the processor receives the data related to the sensor or the actuator. In one embodiment, the data may be retrieved by initiating a request to the sensor or actuator. In another embodiment, the data may be stored in the memory and the processor retrieves the data from the memory **208**. The processor may also retrieve the unique address locations of the data from the memory. Then, the processor formats a transmit signal in response to the command message as described above. The processor then communicates the transmit signal to the transceiver, which provides the transmit signal to the wireless control system. The transmit signal is then delivered to the intended point, such as a monitoring node.

[**0068**] According to an alternate embodiment of the present invention, a sensor node can periodically sample the sensor and the sensor data is aggregated into a local memory for processing and/or transmission. **FIG. 5** is a flow chart illustrating the sensor data processing and routing operation according to one embodiment of the present invention. Referring to **FIG. 5**, the sensor node is programmed to periodically acquire sensor data (step **502**). Then, the sensor data is filtered (step **504**) and/or compressed and/or processed (step **506**). Data compression may be performed to reduce the data transmission requirements and improve the usability of the data by other nodes in the network. Noise filtering can include noise reduction, cross-channel interference reduction, missing sample interpolation and other signal processing to enhance the quality of the data. Compression can include differential coding within a channel or jointly between multiple correlated channels. Processing can include statistical analysis (average, median, standard deviation and higher order correlations), linear regression, linear approximation and other mathematical modeling processes to improve the usability of the data. The processed sensor data is stored in a local memory (step **508**).

[**0069**] The processed sensor data can then be delivered to other wireless nodes in the system as created on a periodic schedule or as requested by other nodes in the system. If the data is delivered as created, or on a periodic schedule, the wireless node should have stored the address of the target network nodes that need to receive the data. If the data is delivered on a periodic basis, the schedule for delivery to a

target network node should be stored. If data is delivered as requested, or on command from another node in the network, the request or command contains the address of the requester to where the data is to be sent.

[0070] At step **510**, synchronous transceiver activation is performed to activate all wireless nodes within the system or within a zone in a system. Then, the sensor data is routed through the network of wireless nodes to the intended recipient, such as the actuator nodes (step **514**), a monitor node (step **516**), and a gateway node (step **518**). The gateway node may forward the message to a remote computer (step **520**). In the case where the sensor data is transmitted to an actuator node, the sensor data is used to control the state of the actuator.

[0071] A distinct difference between the conventional irrigation control system and the control system of the present invention is that no central control unit is required for the operation of the actuators and sensors. In accordance with the present invention, all coordination between actuators, sensors, and other operation points, such as gateways, monitor points user interface point, or user input point, is accomplished across the system through distributed control and without the need for a central controller.

[0072] When the wireless nodes are powered by battery power or solar power, power conservation is important. To conserve power, the transceivers in the wireless nodes can remain powered down. However, to restore end-to-end network connectivity, the nodes must all be active so that messages can be forwarded through the nodes. **FIG. 6** is a flow chart illustrating the transceiver synchronization operation according to one embodiment of the present invention. Referring to **FIG. 6**, in normal operation, the environmental monitoring and control system causes the transceivers of all the wireless nodes to power down (step **602**). Then, when messages are to be transmitted, a synchronization event is used to synchronously bring all nodes out of a powered down state (step **604**). The synchronization event can be time based, such as a particular period or duration agreed to before the nodes are powered down. The synchronization event can also be a combination of time and received wireless synchronization messages. In this case, the wireless nodes wake up the receivers periodically to listen for a synchronization message. The wireless nodes do not start relaying messages until after receiving the network wakeup synchronization message. After a pre-defined period or the receipt of a power-down message, the wireless nodes will power down.

[0073] After the transceiver is activated (step **606**), the transceiver in a wireless node determine if it has a message to send (step **608**). If not, then the transceiver listens for incoming messages (step **610**). If there is a message to be sent, the transceiver determines the route to the destination (step **612**). The transceiver then waits for available channel (step **614**) and when a channel is available, the message is transmitted (step **616**). The transceiver waits for receipt confirmation (step **618**) from the destination node (step **618**). If confirmation is not received within the timeout period (step **620**), then the transceiver returns to step **612** and attempt transmission again. If confirmation is received, then the transceiver checks to see if the synchronization has timed out (step **622**). If so, the transceiver is powered down (step **624**). If synchronization has not yet timed out, then the operation returns to step **608** where the transceiver determines if there is a message to be sent.

[0074] Accordingly to another aspect of the present invention, the wireless environmental monitoring and control system can be applied to security applications. Thus, in an alternate embodiment, the sensor nodes are implemented using smoke detectors, infrared (IR) motion detection, ultrasonic presence detection, and security key detection. The actuator nodes can be implemented as alarms, such as a bell alarm or a visual alarm indicator. Detection of the presence of smoke or motion can be transmitted as messages to the actuator nodes so that the events can be reported accordingly.

C. Scheduled Transmission for Power Saving

[0075] As described above, the wireless nodes, whether a sensor node or an actuator node, are typically battery powered or solar powered and thus power conservation is critical. In accordance with one aspect of the present invention, a scheduled transmission protocol is implemented in the environmental monitoring and control system for promoting efficient power use and power conservation.

[0076] In one embodiment, the receiver nodes schedule all transmission slots. In the present description, the receiver nodes are those wireless nodes receiving transmission of messages. For example, the receiver nodes can be the actuator nodes receiving transmission of sensor data and/or commands from respective sensor nodes. The sensor nodes send message packets at scheduled times and the receiver node responds to transmissions with an acknowledge packet. The acknowledge packet contains the timing information for the sensor nodes' next scheduled packet transmission and the next frequency of transmission (if frequency hopping is used). If the receiver node wants to communicate to the sensor node, the receiver node sends data/command packets to the sensor nodes after receiving packets from the sensor nodes, but before sending the acknowledge packet that terminates the time slot. The benefit of this protocol is that the sensor nodes and receiver nodes can sleep until the next scheduled transmission slot, saving a tremendous amount of power.

[0077] Alternately, instead of having the receiver nodes schedule the transmission slots, the sender nodes can also function to provide scheduling of the next transmission. In the present description, the sender nodes are those wireless nodes that are transmitting messages. In this case, the sender nodes send as a message the timing information for the receiver nodes' next scheduled packet transmission. After the receiver nodes receive and acknowledge the message containing the timing information, the sender node and the receiver nodes power down until the next scheduled time slot. Furthermore, the sender node and the receiver node can also negotiate the next scheduled time slot. In one embodiment, either the sender node or the receiver node publishes to the other node its available timeslots. The node receiving the available timeslots information processes the information and compares the information with its own available timeslot. A desired timeslot is selected and the receiving node sends an acknowledgement message to the sending node to confirm the selected timeslot.

[0078] Thus, according to the present invention, any pair of wireless nodes that want to communicate with each other

can schedule a time slot on an ad hoc basis, depending on the response time requirements of the application. During the communication between a pair of nodes, the nodes determine the start time of the next communication time so that the nodes do not have to use power with their receivers or transmitters on until the next scheduled transmission time. The nodes can turn the power off to the transceiver until the next scheduled transmission time. To further reduce power requirement, wireless nodes should maintain reasonably accurate time bases so that transmissions can be synchronized. The accuracy can be enhanced by timing synchronization packets that are broadcast through the system to all wireless nodes that want to synchronize transmissions. To support global broadcast packets, nodes can schedule a time slot when all nodes are listening. Broadcast packets sent at this time can be received by all nodes listening. To assure all nodes in the network receive the broadcast packets, nodes that receive broadcast packets can re-transmit the broadcast packets for nodes that were not in range of the source of the broadcast packet. Broadcast packets can optionally be acknowledged by the nodes that receive them.

D. Wireless Sensor Probe Configurations

[0079] When the environmental monitoring and control system of the present invention is used for irrigation, it is desirable to have a sensor node that can easily be installed in the ground to measure soil moisture, temperature as well as other properties of the soil and air. **FIG. 7** is a cross-sectional diagram illustrating a sensor node according to one embodiment of the present invention and the installation of the sensor node in the ground. Referring to **FIG. 7, a** sensor node **750** is inserted into the soil **755**. Sensor node **750** includes a collar **752** extends out from a housing or a probe body **751** of the sensor node for anchoring the sensor node above the soil. Also, collar **752** serves to protect the sensor node from encroachment by surrounding plants, reduce the buildup of water around the probe, and reduce grass shading of the probe. Collar **752** may be attached to sensor node **750** or it may be loose or free floating. Sensor node **750** also includes a gasket **756** that extends out from the surface of sensor body **751**. Gasket **756** serves to increase the contact force with the surrounding soil improving the stability of the installed sensor node and reducing the possibility that water will flow down along the side of the sensor body. Gasket **756** is in the shape of a ring, such as a rubber ring. In the present embodiment, sensor node **750** further includes a gasket **758**. Gasket **758** is a gasket structure with an angular shape. The angular gasket structure has a top portion facing the top of the probe body, a bottom portion facing the bottom of the probe body and a side portion having tapered width where the width decreases from the top portion to the bottom portion. Gasket **758** aids in the insertion of sensor node **750**, but prevents the sensor node from being pushed up out of the soil by regular expansion cycles. In other embodiments, the sensor node may include only one gasket.

[0080] In the present embodiment, sensor node **750** further includes raised structure **760** for housing the sensor component. The raised structure improves the contact force between the sensor and the soil. The raised structure also improves the stability of the sensor node in the soil.

[0081] According to another embodiment, the sensor node is implemented using a separable probe body in order to protect sensitive components during installation of the sensor node. **FIGS. 8 and 9** are two embodiments of a sensor node of the present invention constructed using separable probe body. Referring to **FIG. 8, a** sensor node includes a probe body **854** formed with a gasket **852**. The probe body can be inserted into the soil before the sensor circuitry, formed in the form of a sensor mast **856** is inserted into probe body **854**. The top part **850** of probe body **854** includes solar cells formed on the top and a data display and battery slots on the bottom. The data display can be an LED or an LCD display. A connection to the sensor mast is also provided. Referring to **FIG. 9, a** sensor node includes a probe body **954** with a top part **950**. A sensor mast **952**, containing the sensor, the related circuitry and the power circuitry, is formed separate from probe body **954** and can be inserted in probe body **954**. During installation, probe body **954**, without the sensor mast, is hammered or pressed into the soil. After the probe body insertion is complete, sensor mast **952** can be inserted into probe body **954** to complete the installation. In this manner, the sensor node can be inserted into the soil without damaging the antenna, the solar cells, the electronics or other sensitive components on the sensor mast. A gasket (not shown) can be provided on sensor mast **952** to anchor the sensor mast to the inner perimeter of the probe body and to seal the space between the mast and the probe body. The removable top part **950** can then be put in place to enclose the sensor node. The top part can attach by a screw mount, bayonet type mount, or a flanged mount that allows the electrical connections between the top piece and the probe body to be made automatically. In **FIG. 9**, top part **950** can further include a LCD display (not shown) for displaying operating data of the sensor.

[0082] **FIGS. 10A and 10B** illustrate differential embodiments of the sensor nodes of the present invention. In **FIG. 10**A, the top part of the sensor node includes a PC board housing the antenna, the transceiver and the processor circuitry. The battery slot is provided in the body of the sensor mast. In this embodiment, moisture sensors are incorporated in the sensor mast at the bottom of the probe body. In **FIG. 10**B, the top part of the sensor node includes a PC board housing the antenna, the transceiver and the processor circuitry and a compartment for the battery. A series of moisture sensors are installed in the body of the sensor mast.

[0083] In **FIGS. 8 and 9**, the probe body assumes a circular shape. However, in other embodiment, the sensor body can take other shapes as well to suit the needs of the installation. **FIG. 11** illustrates variations on the probe body configuration. Referring to **FIG. 11, a** rectangular probe body **1100**, a hexagonal probe body **1102**, a round or circular probe body **1104**, a triangular probe body **1106** and a cross-beam probe body **1108** are shown. No matter what the shape the probe body assumes, a collar and a gasket can be used to anchor and secure the sensor node.

[0084] The sensor component can be implemented using any suitable sensor types. For example, thin film resistive moisture sensor or thin film capacitive moisture sensor can be used.

E. RF Based Positioning and Intrusion Detection

[0085] With an array of wireless network nodes, it is beneficial to know the relative physical position of the nodes to assist in message routing and also to know the location of

the actuators and sensors associated with the wireless nodes. According to another aspect of the present invention, the wireless environmental monitoring and control system provides positioning determination by measurement of the RF power received from each node and the RF power sent from each node. Specifically, because RF power drops off by the square of the distance from the source, the measurement of the RF power of a received signal defines a distance radius around the receiver where the source can be located. By triangulating the measured RF power from multiple wireless nodes, the position of the wireless nodes can be determined. In one embodiment, the processor in each wireless node monitors the fall of the power level as the object passes between nodes.

[0086] In one embodiment, a wireless node sends out a measurement signal with a message containing the measured transmit power. Each node that receives the measurement signal measures the power and reports it back to the transmitter node. Each node in the network transmits a measurement signal at different times. Each receiving node sends the transmitter node the received power information and the transmitter processes the power information to determine the range of each receiving node. The range information is broadcast back to all receiving nodes. Each node stores the range information from the nodes that it receives data from and uses it to calculate the relative position of each node in the network. To interpret the relative positions into physical positions, it is necessary to know the physical position of at least two nodes in the network. This is used to orient and scale the relative positions.

[0087] According to yet another embodiment of the present invention, the environmental monitoring and control system is configured for occupancy detection or intrusion detection. In this embodiment, the RF transceivers of the wireless nodes are used as sensors to detect the movement of objects in the regions between wireless nodes. **FIG. 12** is a schematic diagram illustrating the use of the environmental monitoring and control system of the present invention for occupancy detection. Referring to **FIG. 12**, an object **1220** is in a position between a wireless node **1206** and a wireless node **1212**. This position affects the measured RF power level of signals sent between the two nodes. By measuring the RF power levels of signals sent between all of the nodes in the network and identifying large changes, it is possible to estimate the location and motion of objects in the region. The detection can be further enhanced by correlating the measurements of the nodes to reduce false alarms and improve precision of the position estimate. To enhance the quality of the detection, it is desirable to know the physical location of each of the transceivers in the network. This can be measured during installation or automatically estimated from RF power measurements as detailed above.

F. Two-Wire Control of Sprinkler System

[0088] According to another aspect of the present invention, a two-wire control system and method for interfacing environmental sensors or other irrigation control data to a timer-based sprinkler controller is described. The two-wire control system allows a wireless sensor network to be incorporated into existing irrigation systems including a central sprinkler controller. The two-wire control system enables precise control over irrigation times for individual zones within a full sprinkler controller cycle. Furthermore, the two-wire control system enables the control of on/off and duration functions for individual zones of an automatic sprinkler controller. In one embodiment, the two-wire control system includes a single relay inserted into the common line return of a timer-based sprinkler controller and a sensing circuit coupled to monitor the voltage or current on the common line. The two-wire control system enables precise control of irrigation durations for individual zones in an irrigation cycle.

[0089] Existing automatic sprinkler controllers for residential and commercial applications are typically wired so that the sprinkler controller provides 24VAC drive signals to each valve in the system by switching one side of the two-wire connection to the valve. The other side/wire to the valve is connected together with the "common" line of all other valves. In this setup, each valve in the system has a single independent connection to the controller and another connection that is common with all of the other valves in the system.

[0090] When an environment sensor is incorporated in such a sprinkler controller system, the sensor data inputs typically operate to completely override the on/off/zone duration information of the sprinkler controller. For example, if a rain sensor detects rainfall it will completely block the irrigation controller from applying water for a duration determined by the rain sensor. This is typically implemented by inserting a relay into the common path and breaking the circuit to block irrigation cycles and making the circuit to enable irrigation cycles. The conventional sensor data integration method thus operates to disable all zones for the duration.

[0091] However, with the two-wire control system of the present invention, it is possible to adjust the on/off and duration of each irrigation zone to provide more precise control of the water applied to a particular zone. This is particularly useful when soil moisture sensors are used or other weather forecasting and control algorithms are used where it is beneficial to be able to adjust the duration as well as the on/off of each irrigation zone.

[0092] In one embodiment, the two-wire control system interfaces sensors/auxiliary decision information to an existing automatic sprinkler system so that precise control of on/off and duration of individual zones in an irrigation cycle is attained. **FIG. 13** is a block diagram of an automatic sprinkler system **1300** incorporating the two-wire control system according to one embodiment of the present invention. Referring to **FIG. 13**, sprinkler system **1300** includes a timer-based sprinkler controller **1302**. Sprinkler controller **1302** provides irrigation control of zone no. 1 to zone no. N. Thus, sprinkler controller **1302** includes a first set of wires coupled to the zone control nodes 1 to N for providing the 24V drive signal to the respective valves no. 1 to N. A common line **1304** connects a common node **1304** to all the valves for establishing the common return path.

[0093] Sprinkler system **1300** includes a two-wire control system **1305** for providing precision on/off or duration control of each irrigation zone controlled by sprinkler controller **1302**. In two-wire control system **1305**, a relay **1306** is inserted into the path of common line **1304** to provide on/off control based on sensor or auxiliary control data. Relay **1306** can be provided outside of the housing of sprinkler controller **1302** or within the controller unit itself.

[0094] Two-wire control system **1305** further includes a sensing circuit **1308** for monitoring the start and stop cycles of each zone so that the system can precisely switch the individual valves on/off to control the duration within the interval defined by the irrigation controller. In the present embodiment, sensing circuit **1308** is coupled to the common line and the system monitors the start and stop times of each zone by measuring the voltage and/or current on the "common line" of the valves. Specifically, the sensing circuit detects the assertion and deassertion of the valves by measuring the voltage and/or current on the common line of the valves.

[0095] In another embodiment, the sensing circuit can be coupled to each of the control line of the zones. The system thus monitors the start and stop times of each zone by measuring the voltage and/or current on each individual control line for the valves. Transitions of voltage and/or current on the "common line" or control lines are used to determine the start/stop of each irrigation zone. Knowing the start and stop time of the control signal for each of the valves enables the control of the relay on the common line to enable each individual zone for any duration within the maximum time for that zone set by the irrigation controller. Two-wire control system **1305** further includes a relay controller **1310** receiving the sensor or auxiliary data input and providing a control signal to relay **1306** for controlling the irrigation cycle of each zone.

[0096] **FIG. 14** is a timing diagram illustrating the operation of sprinkler system **1300** according to one embodiment of the present invention. In **FIG. 14**, the control line for zone no. 1 is asserted at time T1 (see curve ZoneCtl#1) and the common line experience an OFF to ON transition. Control system **1305** detects that zone no. 1 is being turned on as triggered by sprinkler controller **1302**. Relay controller **1310** determines based on the sensor control data input that zone no. 1 should be turned on for the full duration. Thus, relay controller **1310** turns on relay **1306** so that the valve for zone no. 1 is turned on, as shown by the curve labeled ZONE#1.

[0097] At time T2, the control line for zone no. 2 is asserted (see curve ZoneCtl#2) and an OFF to ON transition occurred on the common line. For this irrigation zone, relay controller **1310** determines that the irrigation duration for the zone can be shortened to maintain effective moisture levels. Thus, relay **1306** is only turned on for a short time and is turned off at time T3 which as the effect of turning off the valve for zone no. 2 (see curve ZONE#2). In this manner, two-wire control system **1305** shortens the irrigation cycle for a specific zone.

[0098] At time T4, the control line for zone no. 3 is asserted (see curve ZoneCtl#3) and an OFF to ON transition occurred on the common line. For this irrigation zone, relay controller **1310** determines that the irrigation cycle should be terminated entirely. Thus, relay **1306** is not turned on at all and the irrigation cycle for zone no. 3 is entirely disabled (see curve ZONE#3).

[0099] At time T5, the control line for zone no. N is asserted (see curve ZoneCtl#N) and an OFF to ON transition occurred on the common line. For this irrigation zone, relay controller **1310** determines that the irrigation duration should be shortened. Thus, relay **1306** is only turned on for a short time and is turned off at time T6 which as the effect of turning off the valve for zone no. N (see curve ZONE#N). The irrigation cycle for zone no. N is thus shortened.

[0100] In summary, control system **1305** detects the first transition on the common line (turn-on) or control line, triggered by the irrigation controller to determine the turning-on of a particular zone. The transition can be detected either by detecting discontinuities in the voltage on the common/control lines or by detecting discontinuities in the current through the common/control lines. The next transition on the control lines corresponds to the turning-off of the zone. In this manner, the control system keeps track of the start time and the duration of control signal for each valve. Relay **1306** is thus able to control the interval of each zone from the full duration set by the irrigation controller down to 0 seconds.

[0101] In one embodiment, detection of the voltage on the common line or the control lines can be achieved through the use of a transistor or operational amplifier that saturates when the potential difference on the two contacts of the open relay exceed a specified threshold. Detection of the current in the common line or the control lines can be achieved either by an inductively coupled current detector or by measuring the voltage differential across an in-line resistor.

[0102] The sensor or auxiliary control data can include data from moisture sensors, temperature sensors, or weather measurement sensors.

[0103] According to another embodiment of the present invention, a sprinkler controller can incorporate a relay in series with the common line. In that case, the two-wire control system of the present invention includes a sensing circuit for sensing the on-off duration of each irrigation zone and a relay controller coupled to control the relay in the sprinkler controller based on sensor and auxiliary control data.

[0104] Furthermore, according to another embodiment of the present invention, the sensing circuit of the control system is used to learn the programming of the sprinkler controller that is driving the valves. Basically, the sensing circuit enables the control system to learn the start time and the duration of each individual zone in the cycle. For example, irrigation cycles can start at 4:00AM on Monday, Wednesday and Saturday. This cycle can have independent durations for each zone in the cycle. The controller can also have other programmed cycles that start at a different time, different period and with different durations. For example, an irrigation cycle can start on 10:00AM every other day and with different durations for each zone. The sensing circuit of the present invention monitors the common line and uses the ON-OFF transitions on the common line to learn the programming of the sprinkler controller over time. The control system can use the sprinkler programming information to determine the best time to enable an irrigation cycle, in addition to the soil moisture and other sensor data.

[0105] The above detailed descriptions are provided to illustrate specific embodiments of the present invention and are not intended to be limiting. Numerous modifications and variations within the scope of the present invention are possible. The present invention is defined by the appended claims.

I claim:

1. A method for providing environmental monitoring and control, the method comprising:

providing a plurality of wireless nodes, the plurality of wireless nodes includes a plurality of sensor nodes and a plurality of actuator nodes, each wireless node including a wireless transceiver, a processor and one of a sensor device or an actuator device;

sending a message from a first wireless node to a second wireless node through wireless communication; and

processing the message at the second wireless node,

wherein the message comprises sensor data or a control command operative to control the sensor device or the actuator device in the second wireless node.

2. The method of claim 1, wherein the second wireless node comprises a sensor node and the message comprises a command to request sensor data, the method further comprises:

collecting sensor data at the second wireless node; and

transmitting the sensor data to a destination node in accordance with the message.

3. The method of claim 1, wherein the second wireless node comprises an actuator node and the message comprises a control command for controlling the actuator device, the method further comprises:

controlling the actuator device in response to the message.

4. The method of claim 1, wherein sending a message from a first wireless node to a second wireless node through wireless communication comprises sending a request message from the first wireless node being an actuator node to the second wireless node being a sensor node, the method further comprising:

transmitting sensor data from the second wireless node to the first wireless node upon receipt of the request message.

5. The method of claim 1, wherein sending a message from a first wireless node to a second wireless node through wireless communication comprises:

sending the message from a first wireless node to a third wireless node; and

sending the message from the third wireless node to the second wireless node,

wherein the third wireless node comprises a sensor node or an actuator node.

6. The method of claim 5, wherein the plurality of wireless nodes further includes a repeater node for relaying messages between the wireless nodes, the third wireless node being the repeater node.

7. The method of claim 1, wherein the first wireless node comprises a sensor node and the second wireless node comprises an actuator node, and wherein sending a message from a first wireless node to a second wireless node through wireless communication comprises:

collecting sensor data at the sensor node;

processing the sensor data to generate a control command; and

sending a message containing the control command to the second wireless node for controlling the actuator device of the second wireless node.

8. The method of claim 1, further comprises:

sending a message including sensor data from a third wireless node to the second wireless node, the first, second and third wireless nodes being sensor nodes;

receiving messages including sensor data at the second wireless node from the first and the third wireless nodes;

processing the sensor data to generate a control command for a destination actuator node; and

sending the control command to the destination actuator node.

9. The method of claim 1, wherein the first wireless node and the second wireless node comprise a first and a second actuator node, the first wireless node sending the message to the second wireless node for coordinating a sequence for actuating the respective actuator device.

10. The method of claim 1, further comprising:

transmitting messages from the plurality of sensor nodes to one or more wireless nodes on a periodic time basis, the messages comprising sensor data or control commands.

11. The method of claim 1, further comprising:

transmitting messages including sensor data from all of the plurality of sensor nodes to one or more wireless nodes;

processing the sensor data at the one or more wireless nodes, wherein each of the one or more wireless nodes processes the sensor data associated with the respective wireless node; and

generating control commands at the one or more wireless nodes based on the associated sensor data.

12. The method of claim 1, further comprising:

turning off the wireless transceivers of the plurality of wireless nodes; and

turning on the wireless transceivers of the plurality of wireless nodes synchronously to transmit and receive messages.

13. The method of claim 12, wherein turning on the wireless transceivers of the plurality of wireless nodes synchronously comprises:

turning on the wireless transceivers of the plurality of wireless nodes based on a predetermined time schedule.

14. The method of claim 12, wherein turning on the wireless transceivers of the plurality of wireless nodes synchronously comprises:

turning on the wireless transceivers of the plurality of wireless nodes periodically to listen for a synchronization command; and

turning on the wireless transceivers of the plurality of wireless nodes to transmit and receive messages when a synchronization command is received.

15. The method of claim 1, further comprising:

sending an acknowledgement message from the second wireless node to the first wireless node.

16. The method of claim 1, wherein the first wireless node comprises a sensor node, the method further comprising:

collecting sensor data from the sensor device of the first wireless node; and

sending the message including the sensor data to the second wireless node as sensor data is collected.

17. The method of claim 1, wherein the first wireless node comprises a sensor node, the method further comprising:

collecting sensor data from the sensor device of the first wireless node;

integrating sensor data over a period of time; and

sending the message including the integrated sensor data to the second wireless node.

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