



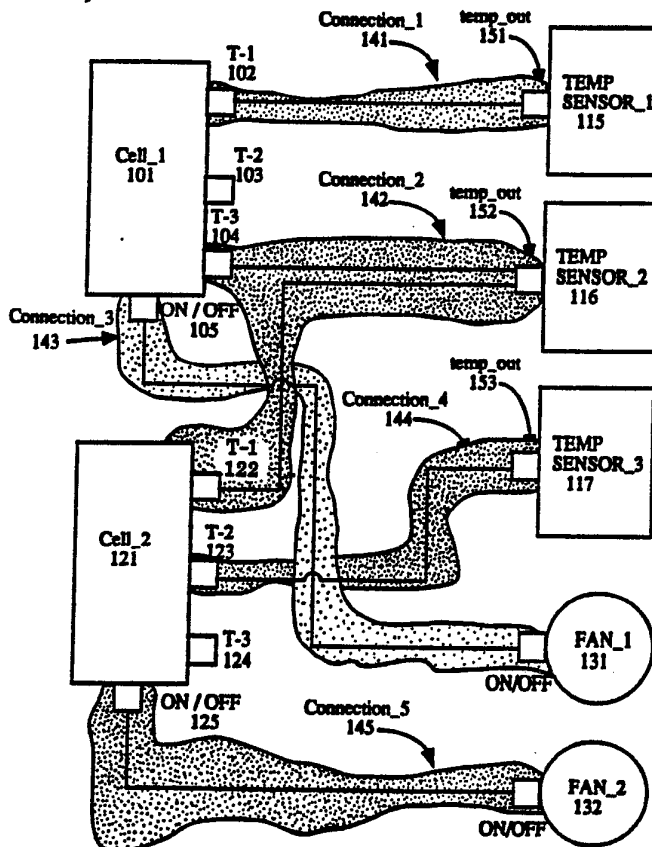
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<p>(21) International Application Number: PCT/US92/02147 (22) International Filing Date: 17 March 1992 (17.03.92) (30) Priority data: 671,036 18 March 1991 (18.03.91) US (71) Applicant: ECHELON CORPORATION [US/US]; 4015 Miranda Avenue, Palo Alto, CA 94304 (US). (72) Inventors: DOLIN, Robert, A., Jr. ; 700 Wallea Drive, Menlo Park, CA 94025 (US). EINKAUF, Robert, L. ; 636 Pinot Blanc Way, Fremont, CA 94539 (US). KAGAN, Richard, S. ; Flat 2, Langland Gardens, London NW3 6QO (GB). RILEY, Glen, M. ; 918 Bicknell Road, Los Gatos, CA 95030 (US). VON DE BUR, James, M. ; 2308 Price Way, San Jose, CA 95124 (US).</p>	<p>(74) Agents: TAYLOR, Edwin, H. et al.; Blakely, Sokoloff, Taylor & Zafman, 12400 Wilshire Boulevard, 7th Floor, Los Angeles, CA 90025 (US). (81) Designated States: AT, AT (European patent), AU, BB, BE (European patent), BF (OAPI patent), BG, BJ (OAPI patent), BR, CA, CF (OAPI patent), CG (OAPI patent), CH, CH (European patent), CI (OAPI patent), CM (OAPI patent), DE, DE (European patent), DK, DK (European patent), ES, ES (European patent), FI, FR (European patent), GA (OAPI patent), GB, GB (European patent), GN (OAPI patent), GR (European patent), HU, IT (European patent), JP, KP, KR, LK, LU, LU (European patent), MC (European patent), MG, ML (OAPI patent), MR (OAPI patent), MW, NL, NL (European patent), NO, RO, RU, SD, SE, SE (European patent), SN (OAPI patent), TD (OAPI patent), TG (OAPI patent).</p> <p>Published With international search report.</p>	

(54) Title: NETWORKED VARIABLES

(57) Abstract

An improved apparatus and method for communicating information in a networked system wherein variables are employed to accomplish such communication. Network variables allow for standardized communication of data between nodes (301-305) in a network. A first node (301) may be programmed, for example, to sense certain information and to report the information as a network variable X. A second node (302) may be programmed to receive the variable X and to control devices based on the current value of the variable. The present invention provides for defining connections (201) between the first and second node to facilitate such communication and for determining addressing information to allow for addressing of messages, including updates to the value of the variable X, between the nodes.



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NETWORKED VARIABLES

BACKGROUND OF THE INVENTION

1. FIELD OF THE INVENTION

The present invention relates to the field of systems for distributed computing, communication and control and, more specifically, communication of information between devices in a distributed computing environment.

2. DESCRIPTION OF THE RELATED ART

In distributed computer systems it is necessary to provide for communication of information between nodes in the system. A number of methods for providing such communication are known in the art.

These methods include message passing techniques in which messages are passed, over a medium, from one node to another in a network. In message passing techniques, messages are built by a sender node and sent to one or more receiver nodes. The message is then parsed by the receiver node in order to correctly interpret the data. Message passing allows the advantage of passing large amounts of data in an expected format. Of course, over time the format of the message may be required to change to support new applications or features. This typically leads to compatibility issues between nodes on the network.

A second technique involves remote procedure calls in which a first node, requiring data which exists on a second node, calls a procedure executing on the second node where the data exists and requests the procedure to manipulate the data and provide a result to the first node. Remote procedure calls are typically suited to passing small

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amounts of data; however, a separate procedure call is typically required for each interchange. Therefore, it is likely in any networking system that over time additional procedure calls will be required in the network as new functions are carried out by the network. The addition of new procedure calls to certain nodes of the network leads to incompatibility between nodes, because the existing nodes do not know of and cannot execute the new remote procedure calls.

A third technique for communication of data in a network involves data sharing. Bal, Henri E., Steiner, Jennifer G., and Tanenbaum, Andrew S., Programming Languages for Distributed Computing Systems, ACM Computing Surveys, Vol. 21, No. 3, September, 1989, pp. 261-322 (hereinafter Bal et al.) describes certain data sharing techniques. A discussion of data sharing may be found in the Bal et al. article at pages 280, et seq. (It should also be noted that a discussion of messaging may be found in the Bal et al. article at pages 276, et seq. along with a general overview of interprocess communication and synchronization.)

Bal et al. describes how parts of a distributed program can communicate and synchronize through use of shared data. Bal et al. states that, if two processes have access to the same variable, communication can take place by one processor setting the variable and the other processor reading the variable. This communication is described as being allowed to take place whether the two processors are both running on a host where the shared data is stored and thus can manipulate the shared data directly, or if the processes are running on

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different hosts and access to the shared data is accomplished by sending a message to the host on which the shared data resides.

Two types of shared data are described: (1) shared logical variables; and (2) distributed data structures. Briefly, shared logical variables are described as facilitating a communication channel between processes through a "single-assignment" property. Initially, a shared logical variable is unbound, but once a value is assigned to the variable the variable is considered to be bound. An example is provided in which the three goals of conjunction:

goal_1 (X, Y), goal_2 (X, Y), and goal_3 (X)

are assumed and solved in parallel by processes P1, P2 and P3.

The variable X is initially unbound and represents a communication channel between the three processes. If any of the processes binds X to a value, the other processes can use this value. Likewise, Y is a channel between P1 and P2. Processes synchronize by suspending on unbound variables. For example, if Y is to be used to communicate information from P1 to P2, then P2 may suspend until Y is bound by P1.

It should be emphasized that in the described concept of shared logical variables, the term binding is used to describe a process of assigning a value to a variable. As will be seen below, the term binding is also used to describe the present invention, however, the meaning of the term is significantly different and the reader is cautioned to avoid confusion between the concepts represented by these two uses of this term. Generally, in the present invention, the term binding is used to indicate a process of associating a variable of one node with a variable

of at least one other node. It is not necessary that the variable of either node has yet been assigned a data value.

Distributed data structures are data structures which may be manipulated simultaneously by several processes. In concept, all processes share one global memory termed "tuple space" or TS. The elements of TS are ordered sequences of values, similar to records in a language such as Pascal. Three operations may take place on TS: (1) "OUT" adds a tuple to TS; (2) "READ" reads a tuple from TS; and (3) "IN" reads a tuple from TS and deletes it from TS. Thus, in order to change the value of a tuple in TS it is necessary to first perform an IN operation, then to manipulate the data, and then perform an OUT operation. The requirement that a tuple must first be removed by the IN operation makes it possible to build distributed systems without conflict between accesses by the various processes.

Bal et al. contrasts distributed data structures with interprocess communication techniques noting that communication accomplished by distributed data structures is anonymous. A process reading a tuple from TS does not know or care which other process inserted the tuple. Further, a process executing an OUT does not specify which process the tuple is intended to be read by.

Bal et al. states that in concept distributed data structures utilizing the tuple space implement conceptually a shared memory, although in implementation a physical shared memory is not required. However, as can be seen, in a system utilizing such distributed data structures a single copy of the data is stored in tuple space whether or not such tuple space is implemented as a single physical shared memory. Separate

copies of the data are not maintained for the various processes or on the various hosts. In fact, maintaining separate copies would lead to data conflict possibilities as the various nodes attempted to coordinate updates of the variable between the various process and hosts. Thus, the reason for requiring use of the IN command to delete a tuple before allowing manipulation of the data represented by the tuple.

The present invention discloses a networked communication system which is perhaps closest in certain concepts to the described distributed data structures. However, it can, of course, be appreciated that certain advantages may be gained from development of a system which utilizes certain features of distributed data structures while retaining flexibility in allowing multiple copies of a data value to be stored on the various nodes.

The present invention discloses certain improved programming language and data structure support for communication, sensing and control as may be used by nodes of the present invention. It is known in the art to allow for scheduling of tasks through use of a programming statement such as a "when" clause or the like. However, in known systems such tasks may only be scheduled to be executed on the occurrence of a predefined event such as may be defined by the compiler writer. Examples of such events typically include expiration of a timer or input pin state changes. Such known systems do not allow for definitions of events, other than such predefined events. It has been discovered that it is useful to provide for definition of events as any valid programming language statement which may be evaluated to a true or false condition.

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Of course, any number of known systems allow for declaration of variables and when declaring such variables certain parameters may be specified which may be set to a state indicative of a desired characteristic of the variable. For example, a variable may be declared as input or output, as a given variable type (e.g., boolean, numeric, etc.). However, once declared such characteristics are static and may only be changed by changing the source program which declares the variables. It has been discovered that it would be useful to provide for a system in which the state of at least certain parameters may be changed during system configuration allowing for greater flexibility in optimizing the system of the preferred embodiment.

Finally, in known systems it is necessary to call certain I/O library procedures to declare and use I/O devices. Such calls to I/O procedures may be quite complex and require significant skill on the part of the programmer to properly code and utilize the routines. The present invention discloses a system having improved methods for declaration and use of I/O devices.

OBJECTS OF THE PRESENT INVENTION

It is a primary object of the present invention to provide for improved communication of information between nodes of a distributed network.

It is more specifically an object of the present invention to provide for improved communication of information in a highly distributed computer system in which a problem may be broken down into small units in which each node accomplishes a small part of the entire

application. In such a system, data communication may be typically accomplished in relatively small units of data—however, significant communication of data between nodes of the network is required.

It is further an object of the present invention to provide for improved communication of information in a distributed computing system by allowing for standard communication techniques between nodes.

It is still further an object of the present invention to provide for improved communication of information by providing certain facilities, structures and tools for such communication.

It is also an object of the present invention to provide improved data structures and programming language support for communication and other aspects of the present invention.

As one aspect of providing such improved data structures and programming language support, it is one aspect of the present invention to provide for declaration of variables having configurable parameters leading to improved ability to maintain and optimize networks of the present invention.

As another aspect of providing such improved data structures and programming language support, it is desired to provide for increased ease in declaring and communicating with I/O devices of the present invention.

As still another aspect of providing such improved data structures and programming language support, it is desired to provide for improved scheduling functions allowing for use of programmer-defined or predefined events in scheduling of tasks to be executed.

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It is also an object of the present invention to provide simplified installation and network maintenance. Such an objective may be accomplished by storing in each node the node's application interface such that nodes may identify themselves and their application requirements to a network management node at installation time and when it is necessary to recover the complete network database.

To accomplish such a simplified installation and maintenance objective, it is a further objective of the present invention to define an interface file format which may efficiently store and allow retrieval of such identification and application requirement information.

These and other objects of the present invention will be better understood with reference to the Detailed Description of the Preferred Embodiment, the accompanying drawings, and the claims.

SUMMARY OF THE INVENTION

A network for communicating information having at least a first and second node is described in which each node includes data storage for storing data representing a variable V and further includes a processor coupled with the data storage. In the case of the first node, the processor may manipulate and write to new values to the variable V. After having updated the variable V with a new value, the processor then assembles and communicates a packet for transmission on the network. The packet includes the new data value for the variable V. The second node then receives the packet and stores the new value for the variable V in its data storage.

In particular, during programming of the first node, it is declared as a writer of the variable V and likewise during programming of the second node, it is declared as a reader of the variable V. During configuration of the network, a communication connection between the first node and the second node is defined and during later communication of message packets, addressing of message packets between the various nodes is accomplished through use of address tables based on the definition of such connections.

Further, it is disclosed to utilize a standardized set of variable types in accomplishing such communication. Use of a standardized set of variable types leads to increased compatibility between nodes of different manufacture as well as increased ease in configuring networks.

Finally, certain extensions are provided to standard programming languages to provide for increased ease of use of the data communication features of the present invention.

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These and other aspects of the present invention will be apparent to one of ordinary skill in the art with further reference to the below Detailed Description of the Preferred Embodiment and the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a logical view of a configuration of devices as may be networked using methods and apparatus of the present invention.

Figure 2 is a diagram illustrating an embodiment of the network of Figure 1 as may be accomplished by the present invention.

Figure 3(a) is a diagram illustrating a second embodiment of the network of Figure 1 as may be accomplished by the present invention.

Figure 3(b) is a second diagram illustrating the second embodiment of Figure 3(a) and including a logical view of certain connections of nodes of the network.

Figure 4 is an overall block diagram of a single node of the present invention coupled with a communication medium.

Figure 5 is an overall flow diagram illustrating a method of programming and configuring a network as may be accomplished by the present invention.

Figure 6 is a flow diagram illustrating a method for defining hardware requirements of a node as may be utilized by the present invention.

Figure 7 is a flow diagram illustrating a method for defining network and logical parameters of a node as may be utilized by the present invention.

Figure 8(a) is a flow diagram illustrating a method for defining connections among network variables as may be utilized by the present invention.

Figure 8(b) is a flow diagram illustrating a method for binding network variables as may be utilized by the present invention.

Figure 9 is an illustration of certain data structures which may be utilized by the present invention.

Figure 10 is a flow diagram illustrating a method of configuring a network using standard network variable types, as may be utilized by the present invention.

Figure 11 is a flow diagram illustrating a method of declaring and configuring a network variable as may be used by the present invention.

Figure 12 is a flow diagram illustrating a method of declaring and accessing I/O devices as may be utilized by the present invention.

For ease of reference, it might be pointed out that reference numerals in all of the accompanying drawings typically are in the form "drawing number" followed by two digits, xx; for example, reference numerals on Figure 1 may be numbered 1xx; on Figure 9, reference numerals may be numbered 9xx. In certain cases, a reference numeral may be introduced on one drawing, e.g., reference numeral 201 illustrating a communication medium, and the same reference numeral may be utilized on other drawings to refer to the same item.

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DETAILED DESCRIPTION OF
THE PREFERRED EMBODIMENT

An improved computer network including facility for communication of information between nodes in the network is described. In the following description, numerous specific details are set forth in order to provide a thorough understanding of the present invention. It will be obvious, however, to one skilled in the art that the present invention may be practiced without these specific details. In other instances, well-known circuits, structures and techniques have not been shown in detail in order not to unnecessarily obscure the present invention.

OVERVIEW OF THE NETWORK
OF THE PRESENT INVENTION

The network of the preferred embodiment is of the type which provides for sensing, control and communication. The network of the present invention and nodes utilized within the network of the present invention are described in greater detail with reference to United States Patent No. 4,918,690 Markkula et al. titled "Network and intelligent cell for providing sensing, bi-directional communications and control", which patent is assigned to the assignee of the present invention (referred to herein as the '690 patent).

In an exemplary network, the network of the present invention may provide for sensing of current environmental factors and control of apparatus affecting the environmental factors. Further, the network may allow for communication of information packets providing information on the environmental factors between nodes in the network. The present application will utilize, as an example, a network for control of fans based

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on sensing and communicating information regarding temperature in different zones in a controlled environment.

It might be worthwhile noting that in an expected scenario, various manufacturers will include a node of the type defined by the present invention in their products. For example, a thermostat manufacturer may include such a node in its thermostats. A fan manufacturer may include such a node in its fans. The various nodes may be programmed for specific applications by their respective manufacturers and, when configured in an environmental control system, are useful for communication, sensing and control between various components of the system. A node of the preferred embodiment is illustrated in block diagram form with reference to Figure 4. Such nodes may be programmed, for example, using the "C" computer programming language. As one aspect of the present invention, certain extensions have been provided to the "C" language to facilitate network communications.

As a further and important aspect of the present invention, network variables are described which provide for communication of information between nodes of the network. A network variable may be thought of as a data object shared by multiple nodes where some nodes are "readers" and some nodes are "writers" of the object. This will be discussed in greater detail below.

A network as may be implemented utilizing the present invention

Referring now to Figure 1, a logical view of a network as may utilize the present invention is shown. The network may, for example, include three separate temperature sensors 115-117 located in three

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separate zones of a building for sensing and communicating temperature information. The network may further include two control cells 101 and 121 coupled to receive temperature information from the sensors 115-117 and to control two fans 131-132 (by turning the fans 131-132 on and off).

In the exemplary network, network variable temp_out 151 is coupled to a first network variable temperature input 102 of control cell 101. Network variable temp_out 152 is coupled with a second network variable temperature input 104 of control cell 101. In the illustrated embodiment, a third network variable temperature input 103 is not utilized. On/Off control network variable 105 of control cell 101 is coupled to control an input network variable, On/Off, of a fan 131. Thus, in this embodiment, sensing a temperature above a given level in the zone of the building sensed by temperature sensor 115 or by temperature sensor 116 will cause fan 131 to be turned on. Likewise, when the temperature in these zones is again lowered below a given level, the fan 131 may be turned off.

Network variable temp_out 152 is also coupled to a first temperature input network variable 122 of control cell 121. In addition, network variable temp_out 153 is coupled to a second temperature input network variable 123 of control cell 121. A third temperature input 124 of control cell 121 is not utilized in this embodiment. Control cell 121 is coupled through an On/Off control output network variable 125 to control fan 132. Thus, sensing a temperature above a given level in the zone of the building sensed by temperature sensor 116 or by temperature sensor 117 will cause fan 132 to be turned on. Likewise, when the temperature

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in these zones is again lowered below a given level, the fan 132 may be turned off. As is appreciated, in the described configuration, when temperature sensor 116 detects a high temperature, both fan 131 and fan 132 are turned on.

Figure 1 has been labeled to illustrate logical connections between the various components. Connection 141 is illustrated as the connection between temperature sensor 115 and control cell 101. Connection 142 is illustrated as the connection including temperature sensor 116, control cell 101 and control cell 121. Connection 143 is illustrated as the connection between control cell 101 and fan 131. Connection 144 is illustrated as the connection between sensor 117 and control cell 121. Connection 145 is illustrated as the connection between control cell 121 and fan 132. The connection of network variables will be discussed in greater detail below. However, it may now be useful to introduce three new terms: network variables, readers, and writers. In addition, general definitions for certain other terms used in this specification may be found with reference to Table XV.

As one important aspect of the present invention, the present invention provides for allocation and use of network variables by processes running on nodes in a network. As stated above, network variables may be thought of as a data object shared by multiple nodes where some nodes are "readers" of the object and other nodes are "writers" of the object. Additionally, a node may be both a reader and a writer with "turnaround". Writing with turnaround is discussed in greater detail below. Although the data object may be thought of as being shared by multiple nodes, as will be understood from the discussion

below, the network variable of the preferred embodiment is not stored in shared memory but rather separate memory is provided in each of the multiple nodes to store a copy of the data object. A writer node may modify the value of the data object and all reader nodes of that network variable have their memories updated to reflect the change. Thus, for example, each of the temperature sensors 115-117 may run a process which declares a data object as follows:

network output boolean temp_high.

Each of the controller cells 101 and 121 may declare data objects as follows:

network input boolean temp_high

network output boolean fan_on.

Each of the fans 131-132 may declare a data object as follows:

network input boolean fan_on.

The complete syntax for declaration of network variables in the system of the preferred embodiment is given in Table VIII. The keyword "network" indicates the data object is a network variable. A network variable declared as output will result in transmission of the new value of the network variable on the network when the program stores the variable—thus, nodes having declared an output network variable are considered writer nodes for that variable. For example, each time a process running on temperature sensor 115 stores the variable temp_high, a network message is generated communicating the new value of temp_high. The message is communicated to all reader nodes connected in connection_1 141, i.e., to control cell 101. In the case of temperature sensor 116 changing the value of its temp_high variable, a

message is generated and transmitted to all nodes connected in connection_2 142, i.e., to both control cell 101 and to control cell 121. The process for configuring connections as disclosed by the present invention will be discussed in greater detail below.

Although the preferred embodiment declares nodes as either writers or readers of network variables, it should be noted that in an alternative embodiment a node may be declared as both a reader and writer of a particular variable. Such an embodiment may be envisioned without departure from the spirit and scope of the present invention.

It might be that the present invention in its preferred embodiment allows an output network variable to be initialized using an initialization command without causing a message to be transmitted on the network. Using this command, a node may be initially configured or reset without affecting other nodes on the network.

Network variables declared as input may change values asynchronously with program execution—this declaration is used for "reader" nodes. In the preferred embodiment, input network variables may also change values at program initialization or at other points under program control; however, the changed value will not be transmitted on the network.

At anytime, a reader node may force an update of its input network variables utilizing a polling function of the present invention. When this function is called, the specified network variables are updated by requesting over the network the current value from the writer node or nodes. This facility may be useful, for example, after a node reset to allow the node to determine the current value of network variables

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without need to wait until the next time the writer nodes update the value of those variables.

Thus, temperature sensors 115-117 are writer nodes of the variable temp_high. Control cells 101 and 121 are reader nodes of the variable temp_high and also are writer nodes of the variable fan_on. Fans 131-132 are reader nodes of the variable fan_on.

Of course, many other applications and configurations are within the scope of the teachings of the present invention and the network described with reference to Figure 1 is merely exemplary.

It should be noted that multiple readers and multiple writers may be provided within a single connection without departure from the spirit and scope of the present invention. Multiple readers are illustrated with reference to connection_2 142. Multiple writers have not been illustrated by Figure 1. However, variation in which multiple writers are employed will be readily apparent to one of ordinary skill in the art.

Turning to Figure 2, an embodiment of the network of Figure 1 is illustrated in which each of cell 101, cell 121, temperature sensor 115, temperature sensor 116, temperature sensor 117, fan 131 and fan 132 are each coupled to communicate over common communication medium 201. The communication medium 201 may be, for example, twisted pair wiring, radio frequency, power lines, or other communication channels or multiple physical channels connected together with bridges and/or routers. In this embodiment, and in order to accomplish the connections illustrated by Figure 1, temperature sensor 115 must be configured to address and communicate with cell 101; temperature sensor 116 must be configured to address and communicate with cell 101 and cell 121;

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temperature sensor 117 must be configured to address and communicate with cell 121; control cell 101 must be configured to address and communicate with fan 131; and control cell 121 must be configured to address and communicate with fan 132.

Of course, providing for such addressing may be and typically is a significant task. It is appreciated that each of control cells 101 and 121, temperature sensors 115-117 and fans 131-132 may be engineered, programmed and/or manufactured by different sources. Further, although the exemplary network is, in itself, complicated having 5 separate connections, 141-145, it can of course be imagined that other networks may be substantially more complicated having even hundreds or more connections. Therefore, the present invention implements methods and apparatus which allow for straightforward and efficient configuration of nodes in a network.

Turning now to Figure 3(a), a modified embodiment of the configuration of Figure 2 is illustrated. In this embodiment, controller cells 101 and 121 have been removed from the configuration and each of temperature sensors 115-117 and fans 131-132 are illustrated as comprising nodes 301-305, respectively. These nodes are preferably of the type which are capable of sensing, communicating and controlling as have been described in the '690 patent and which are shown in greater detail with reference to Figure 4. Thus, these nodes 301-305 are capable of replacing certain control functions of the control cells 101 and 121, eliminating the need for separate control cells in the described embodiment. In the embodiment of Figure 3(a), and in order to accomplish the logical connections illustrated by Figure 1, node 301

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must be configured to communicate with node 304; node 302 must be configured to communicate with nodes 304 and 305; and node 303 must be configured to communicate with node 305. Again it is important to note that the temperature sensors 115-117 and fans 131-132 may be manufactured by different sources. It is preferable that the manufacturing sources are not required to have prior knowledge as to what devices their products will communicate with in a network. Thus, the manufacturer of temperature sensor 115 is preferably not required to be aware, during programming and manufacture of temperature sensor 115, whether temperature sensor 115 will be configured in a network to communicate with a controller cell, such as controller cell 101 (as shown in Figure 2), or to communicate directly with a fan, such as fan 131 (as shown in Figure 3(a)), or even with some other device (perhaps a heater, air conditioner, fire extinguishing equipment, etc.). Likewise, it is preferable that the manufacturer of fans 131-132 are similarly allowed to manufacture devices without requirement of prior knowledge as to the eventual uses of those devices in a network.

In order to allow for such flexibility in configuring networks and to allow for efficient communication between nodes in a network, the present invention provides network variables which may be used to facilitate standards of communication between nodes in the network.

Table I illustrates a temperature sensor control program as may be used to program nodes 301-303 coupled with temperature sensors 115-117. As can be seen, the program of Table I is written to communicate onto the medium 201 a network variable indicative of the state of temp_in. The value of this variable may be, for example, used by

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a control program running on a control cell, such as control cell 101 or 121, or used directly by a control program running on a fan, such as fans 131-132.

Table II illustrates a fan control program which may be used for controlling a fan such as fans 131-132 by turning the fan on and off responsive to receiving changes in state of a network variable on_off. As can be seen, the program of Table II is written to allow receiving from the medium 201 the network variable on_off as a binary network variable regardless of the source (e.g., whether from a control cell such as control cell 101 or 121, or directly from a temperature sensor, such as temperature sensor 115-117).

Table III illustrates a binding set which connects temperature sensors 115-117 with fans 131-132 as illustrated by Figure 3(a). Figure 3(b) is provided to further an understanding of the binding set. As can be seen, the binding set provides for three connections illustrated as temp1_controls 321, temp2_controls 322, and temp3_controls 323 of Figure 3(b). The connection temp1_controls connects the output variable temp_high of temperature sensor 115 with the input variable fan_on of fan_1 131. The connection temp2_controls connects the output variable temp_high of temperature sensor 116 with the input variable fan_on of both fan_1 131 and fan_2 132. Finally, the connection temp3_controls connects the output variable temp_high of temperature sensor 117 with the input variable fan_on of fan_2 132.

It should be noted that although tables I, II and III illustrate programs which are useful for illustrative concepts of the present invention, an attempt has not been made to ensure these programs are

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syntactically correct. Rather, these programs are provided for the exemplary teaching of concepts of the present invention. It is understood from an examination of the programs of tables I and II that the program of Table I may write the variable temp_high without regard to the eventual recipient of the variable and likewise the program of Table II may read the variable fan_on without regard to the writer node of the variable. Thus, these programs work equally well in a network such as illustrated by Figure 2 including separate control cells 101 and 121 or in a network such as illustrated by Figure 3(a) which does not include such control cells. The binding set illustrated by Table III determines the relationship between the various nodes of the network. Table IV illustrates a binding set which may be used to establish connections in a network such as illustrated by Figure 2.

A node of the present invention

Figure 4 illustrates a block diagram of a node such as nodes 301-305 as may be utilized by the present invention. The node 421 is coupled in communication with medium 201 through control 411, clock and timer circuitry 412, and communication port 408. In addition, the node provides a general purpose I/O port 407 allowing for communication with various external devices. The node further comprises three separate processors 404-406, a read only memory (ROM) 403, a random access memory 402, and an EEPROM 401. The processors 404-406 are useful for executing programs such as the programs illustrated in Tables I and II, as well as other communication, control and operating programs. The ROM 403 may be useful for storing such programs. As will be seen, the EEPROM 401 may be useful for

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storing certain data values which, although configurable, are not subject to frequent changes in value. Each of the processors 404-406, ROM 403, RAM 402, EEPROM 401, control 411, clock 412, I/O port 407, and communication port 408 are coupled in communication through internal address bus 410, internal data bus 420 and timing and control lines 430.

PROGRAMMING AND CONFIGURING

A NETWORK OF THE PRESENT INVENTION

Turning now to Figure 5, steps for programming and configuring a network of the present invention are illustrated. It should be noted that steps illustrated by Figure 5 are implemented in a development system which allows for development and management of networks such as may be implemented by the present invention. However, certain of these steps may also take place outside of the development environment (e.g., connection of network variables and binding). The development system is an integrated hardware and software environment that operates in conjunction with a host computer, an IBM PC/AT compatible in the currently preferred embodiment, allowing a manufacturer or other party to design and build components compatible for communication with a network of the present invention.

The development system includes an IBM PC/AT-compatible computer having an interface adapter card for coupling with a control processor located in a separate card cage. In addition to the control processor, the card cage may hold other cards designed to emulate routing functions in a network and transceiver evaluation boards allowing evaluation of the physical interface with various media, e.g., twisted pair, power line, or radio frequency.

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Initially certain hardware parameters are defined for each node in the network, block 501. This step includes naming or otherwise identifying the node, block 601. A node type is specified, block 602. In the development environment, the node type may be specified as the control processor, an emulator board, or a custom node type. The location of the node is then specified—the location specifies whether or not the node resides in a card cage and, if the node resides in a card cage, the card cage number and slot number, block 603. Next, the channel to which the node is connected is specified, block 604, and the channel's priority is specified, block 605. If the node has been assigned the priority privilege, then the node's priority is set at this time. Finally, certain hardware properties may be specified, block 605. Hardware properties may include model numbers for the node, clock rates, operating system revision levels, ROM size, RAM size, EEPROM size, RAM start address, and EEPROM start address. Finally, the hardware definitions are downloaded to the node, block 606.

Next, network and certain logical parameters are specified for each node, block 502. Currently, this step involves specifying a node name, block 701, and then specifying a program file, block 702, and hardware device name, block 703 associated with the node. Hardware names were specified above in step 601. Program files will be discussed in greater detail below in connection with block 503. The definition of the node is then saved, block 704.

The development environment provides an editor for developing and editing program code, block 503, such as the code illustrated in tables I and II. The preferred embodiment allows programming in the "C"

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language and, further, provides certain extensions to the "C" language which will be discussed in greater detail below. After developing program code, the programs are compiled, linked and loaded as executable programs, block 504, onto the nodes specified in definition of network and logical parameters, block 502.

Connections are then specified for the network, block 505. This step is better illustrated with reference to Figure 8(a). Initially, a connection name is entered (for example, the connection names specified in the binder script of Table III are temp1_controls, temp2_controls and temp3_controls), block 801. In the preferred embodiment, the connection name is entered as a unique name having from one to 16 characters consisting of letters, numbers and underscores; no spaces are allowed.

Next, a node name is selected, block 802. In the preferred embodiment, a list of defined nodes (i.e., nodes which have been previously defined as described in connection with block 502) is displayed and a valid node name may be selected from the displayed list. For example, the node temp_sensor_1 may be selected. After selecting a node name, block 802, a network variable name is selected, block 803. Again, a list of network variable names for the selected node are preferably displayed and a network variable name is selected from the displayed list. For example, the network variable temp_high may be selected.

After completing this process for a first node, a second node may be selected, block 804. Again, a node list is preferably displayed and the second node is selected from the displayed node list. For example, the

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node fan_1 may be selected. A network variable associated with the second node is then selected, block 805, again preferably from a displayed list. Continuing the example, the selected network variable may be fan_on.

Finally, certain parameters may be set, block 806. In the preferred embodiment, settable parameters include the retry count set to the maximum number of times the message will be sent, the retry timer for acknowledged services, and the repeat timer for unacknowledged/repeated messages. This aspect of the present invention will be discussed in greater detail below.

The connection is then added to a connection list using an add function, block 807. It is noted that if additional nodes are to be connected in the connection, they are specified in a similar manner to the first and second nodes after having specified the first and second nodes. An example of such a connection is illustrated in Table III as temp2_controls which includes three nodes: temp_sensor_2, fan_1 and fan_2.

The process of Figure 8(a) is repeated for each desired connection. In the case of the binding set of Table III, the process is repeated three times: (1) once for the connection named temp1_controls; (2) once for the connection named temp2_controls; and (3) once for the connection named temp3_controls. In the case of the binding set of Table IV, the process is repeated five times, once for each of connection_1, connection_2, connection_3, connection_4, and connection_5.

In the preferred embodiment, the output of the connection process is a binary script file that provides commands to drive the subsequent binding process. In order to provide a textual version of what this binary file looks like, Table III and Table IV have been provided.

It is also within the power of one of ordinary skill in the art to develop a graphical user interface for drawing the connections between iconic representations of the nodes and creating a binder script based on such drawings.

Finally, the network variables are bound, block 506, to their respective nodes in order to allow communication within the connections defined during execution of the steps of Figure 8(a). The preferred method of binding network variables is described in greater detail with reference to Figure 8(b).

Initially, the list of connections developed during execution of the steps of Figure 8(a) is read, block 821. Then, certain type checking and message constraint checking is performed for each connection, block 822. The type and message constraint checking includes the following checks:

- (1) Ensure that there are at least two members in each connection;
- (2) Ensure that there is at least one output member and one input member for each connection;
- (3) In the preferred embodiment, no more than one input and one output network variable from the same node may appear in the same connection;
- (4) A warning is given if polled output variables are not attached to at least one polled input;

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- (5) An estimate for message rates may be declared for network variables; a warning is given if the estimated message rates do not match for all members of a connection;
- (6) Network variables may be synchronized or non-synchronized—a warning message is provided if synchronized variables are bound to non-synchronized variables;
- (7) Network variables may be sent as authenticated—a warning is provided if some, but not all, members of a connection are declared as authenticated; and
- (8) Variable types are checked field-by-field for size and sign type matching and for type definition matching. The currently preferred list of type definitions are provided in Table V.

After completing type and message rate constraint checking, the addressing mode for the network variable is determined, block 824. If there is only one destination (e.g., temp1_controls), subnet-node addressing is used using the subnetnode structure given below to create an entry in address table 901. Address table 901 will be discussed in greater detail below. The address entered in the address table 901 is the address of the destination node (e.g., in the case of temp1_controls, the address of fan_1 is entered in the address table of temp_sensor_1; conversely, the address of temp_sensor_1 is entered in the address table of fan_1 to allow for such functions as polling of the current status of the network variable). The address table index entry 912 is set to correspond to the location in the address table 901 corresponding with the address entered in the address table 901. For example, in the case

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of the bind set of Table III, if the address of FAN_1 is entered as a network address 913 in the address table 901 at entry 001, the address table index entry 912 of the network variable table 903 corresponding to the network variable id assigned to the connection temp1_controls is written with the address 001. In this way, whenever messages are sent on the network by temp_sensor_1 indicating the value of temp_high has been updated, the address table index is used to lookup the address of the destination node of such a message. A message is then sent, addressed to the destination node, including the network variable id and the new value. The destination node then receives the message and is able to update the value of its corresponding network variable "fan_on".

If there is more than one destination node (e.g., temp2_controls), group addressing is used using the above group address structure to create an entry in the address table 901. In the case of group addressing, a set of sender and destinations for the network variable is constructed. For example, in the case of the connection temp2_controls, the set of sender and destinations includes temp_sensor_2, fan_1 and fan_2.

Other optimization steps are also provided by the binder of the preferred embodiment and are described in further detail below.

After determining an addressing mode, for each unique set of sender and destinations (unique without respect to which nodes are senders and which nodes are receivers), a group address is assigned to the set, block 825. The group address is propagated to the address table of each of the nodes in the set and stored in their respective address tables 901. The address table index value 912 for the entry

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corresponding to the group address is updated to index the address table 901 at the new entry. For example, group1 is defined to include temp_sensor_2, fan_1 and fan_2 and the group address is stored at entry 002 of the address table 901. Then, the address table index 912 for each of the three nodes temp_sensor_2, fan_1 and fan_2 is updated to point to the new address table entry.

For group address table entries, as described above, only the output network variable nodes actually set their network variable table entries to index the address table. The nodes with input network variables will not index the address table. This allows the same network variable to reside in several network variable connections, and many network variable groups. When an incoming message arrives for one of these input network variables, the correct network variable table entry is found using the network variable ID (the software matches the network variable ID in the message to one in the table).

This "intersecting connection" ability makes the network variable concept more powerful by allowing the same variable to be updated by several groups, thus reducing both the overall network traffic and reducing network variable table space by sharing the same table entry among several connections.

Finally, a single network variable identification number (netvar_ID) is assigned to each network variable in the connection, block 823. This may be better understood with reference to Figure 9 which illustrates a network variable table 902 having a network variable identification field 911 and an address table index field 912. Further, an address table 901 is illustrated having a network address field 913. It should be noted that

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these tables preferably reside in each individual node's EEPROM 401 and have additional fields in the preferred embodiment. However, for simplicity only the above-mentioned fields are illustrated in Figure 9. The network variable table is preferably of a structure as follows:

```

struct nv_table
{
    unsigned priority:1; /*1=priority network variable, 0=non-priority nv*/
    unsigned dir:1;     /*direction 0=input, 1=output*/
    unsigned idhi:6;    /*network variable id, most significant bits*/
    unsigned idlo;      /*network variable id, least significant bits*/
    unsigned ta:1;      /*turnaround: 1= turnaround*/
    unsigned st:2;      /*service*/
    unsigned auth:1;    /*authenticated: 1=authenticated*/
    unsigned addr:4     /*address table index*/
};

```

where the priority field indicates whether messages to update the network variable are to be sent as priority or non-priority messages; direction indicates the direction of the target ID, for example, a network variable update going from an output variable to an input variable would have the direction bit set to a 0; the network variable id is a 14 bit identification number allowing for a maximum of 16,384 unique network variables per domain in the network and corresponds to the network variable id 911 of Figure 9; turnaround indicates an output network variable may be connected to an input network variable of the same node; service indicates whether acknowledged or unacknowledged services is utilized; auth indicates whether message are authenticated prior to being accepted and processed by identifying the sender node through an authentication process; priority indicates whether messages are transmitted as priority or normal messages; and the address table index corresponds to address table index 912 and is an index into the address table 901.

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The Address Table preferably follows one of two formats given below; the first format is for group address table entries and the second format is for single destination node address table entries:

```

struct group
{
    unsigned type:1;      /*indicates whether the structure is for a group or
                          single node*/
    unsigned size:7;     /*group size (0 for groups > 128 members*/
    unsigned domain:1;   /*domain reference*/
    unsigned member:7;   /*node's member # (0 for groups > 128
members*/
    unsigned rptimer:4;  /*unacknowledged message service repeat
timer*/
    unsigned retry:4;    /*retry count*/
    unsigned rcvtimer:4; /*receive timer index*/
    unsigned tx_timer:4; /*transmit timer index */
    int group;          /*group id*/
}

struct subnetnode
{
    unsigned type;      /*indicates whether the structure is for a group or
                          single node*/
    unsigned domain:1;  /*domain reference*/
    unsigned node:7;    /*node's #*/
    unsigned rptimer:4; /*unacknowledged message service repeat
timer*/
    unsigned retry:4;   /*retry count*/
    unsigned rsvd:4;    /*reserved*/
    unsigned tx_timer:4; /*transmit timer index */
    int subnet;        /*subnet*/
}

```

It should be noted here that many of the present invention's concepts of groups, domains, subnets, acknowledged messages, etc. are described in greater detail with reference to United States Patent Application Serial Number 07/621,737 filed December 3, 1990 titled Network Communication Protocol (the '737 application) which is assigned to the assignee of the present invention and which is incorporated herein by reference.

Continuing with the description of assigning a network variable id to a connection, block 823, the first unassigned network id is assigned to the connection and the network variable id is written to the network

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variable table 902 for each node using the network. Thus, in the above example, the network variable id 00000000000002 may be assigned to the connection temp1_controls of Table III; the network variable id 000000000000012 may be assigned to the connection temp2_controls of Table III; and the network variable id 000000000000102 may be assigned to the connection temp3_controls of Table III. It should be noted that network variable ids need not be unique domain wide, but only need be unambiguous within the nodes involved.

Certain advantages gained through use of network variables have now been described such as the ability to automatically generate network addressing schemes from application level connections. In addition to allowing for such ease of use, network variables lead to generally smaller and less complicated application programs over other forms of network communication, such as prior art messaging techniques. Tables V and VI better illustrate differences between and certain advantages of use of the present invention's techniques over, for example, prior messaging techniques. Table V is a program written using network variables of the present invention. Table VI is a functionally equivalent program written using prior art messaging techniques. It is useful to note the comparative program statistics at the end of each program listing in which it is shown that the message program requires 626 bytes of ROM; 177 bytes of EEPROM; and 1314 bytes of RAM. By way of comparison, the network variables program requires only 335 bytes of ROM while using 231 bytes of EEPROM and only 1126 bytes of RAM.

SELF-IDENTIFYING STANDARD NETWORK VARIABLE TYPES

It is desirable to provide for interoperability between nodes in a network. To provide for such interoperability, it is necessary to assure compatibility between network variables in the various nodes of a network. To facilitate such compatibility, as one feature of the present invention, a list of standard network variable types is provided by the assignee of the present invention. The currently preferred list of standard network variable types is provided as Table VII. By utilizing the list of standard network variable types, nodes in the network may be interrogated for information on the network variables employed by the node and the network may then be configured based on this information. This process is better illustrated with reference to Figure 10.

Initially, a node which must be configured is coupled to the network medium, block 1001. After the node is coupled to the medium, an address of the node may be determined through any number of methods. At least one of such methods is described with reference to the '737 application. After having determined an address for the node, messages may be communicated to the node over the medium. In the preferred embodiment, a network management node is coupled to the medium which is useful for configuring the network. The network management node may communicate a command to the new node requesting its information on the network variables employed by the node, block 1002, or may alternatively read such information from a file which has already been placed in the network management node's memory.

In the preferred embodiment, in order to allow for the information to be stored in the network management node's memory, such information is made available for importation into the network management node via a binder interface file (BIF). The BIF file is a byproduct of the compilation process for each node, and contains all the information necessary to install the node on the network. This information is also referred to as the exposed interface of the node.

The BIF file for a new node may be provided to the network management node prior to installation of the new node on the network in order to allow a complete network database to be constructed in advance of, and separate from, the physical installation of the new node on the network. For example, the BIF file may be supplied to the network management node on diskette, over phone lines, or on through other computer readable media.

Information equivalent to the information stored in the BIF file is also preferably stored in the memory of the node. In this case the preferred embodiment confines the application writer to use of a list of standard network variable types when developing an application program designed to run on the node. The list of standard network variable types used by the system of the preferred embodiment is enumerated in Table VII. Use of the list of standard network variables minimizes the required space for storing the exposed interface in the node's memory. Storing the exposed interface in the node's memory offers the advantage of allowing the information to be retrieved without need for the network management node to include a floppy disk drive or other device for receiving externally communicated computer readable

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information. However, absent the option of providing the BIF file over such an external interface, the node must be physically connected on the same network with the network management node prior to construction of the network database. In the preferred embodiment, both options are available and the choice of how the exported interface is imported into the network management node is left up to the node designer.

The file layout for the BIF file of the preferred embodiment is given in Table IX. An example of a BIF file is given in Table X. This exemplary BIF file has been generated for the program given in Table V.

As was mentioned, in the preferred embodiment nodes may utilize the standard network variable types in declaration of network variables. The information describing its network variables is communicated (or exposed) by the node to the network management node, block 1003, using standard messaging features of the network. It will be understood that in alternative embodiments, information describing other, non-standard variable types may also be communicated in a manner similar to communicating the information on standard network variables.

The network management node receives the exposed network variable information, block 1004, and may then use information, including the network variable type, in verifying valid connections and in the binding process. Only network variables of identical types may be bound together in a single connection—thus, use of standard network variable types facilitates interoperability of nodes in the network as well as facilitating identification of network variables when a command is issued to expose the network variables of a node.

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As one extension to the concept of self-identifying standard network types as just described, it is possible to include in the information transmitted responsive to receiving the command to expose network variable's text strings and even graphical icons to the network management node. Such information would make the nodes largely self-documenting.

EXTENSIONS TO THE "C" LANGUAGE

The present invention has implemented certain extensions and features to the "C" programming languages to support use of network variables—these extensions include (1) the already disclosed declarations of variables as network variables and the ability to declare such variables as standard network variable types; (2) declaration and use of I/O objects; and (3) scheduling clauses. Each of these extensions will be discussed in greater detail below. It should be noted that although the extensions have been preferably implemented in the "C" programming language, the idea and concepts of these extensions are not limited to use in this programming language and, in fact, these ideas and concepts may readily be extended to other programming languages.

Network variable declarations

As has been discussed, the present invention provides for declaration of network variables in C programs. Importantly, the declaration of network variables allows for declaring certain information for use by the above-described binding process. This process is better understood with reference to Figure 11. Initially, a network variable is declared in a computer program intended to run on a node of the network of the present invention, block 1101. The preferred format for the

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declaration may be found with reference to Table VIII, below. As can be seen with reference to Table VIII, the declaration format preferably includes a set of parameters called `bind_info`. These parameters allow the network variable to be declared with an initial specification of protocol services. When the program is compiled, this initial information is output as part of the BIF file. The format of the BIF file may be found with reference to Table IX. As one option in declaring network variables, these parameters may be declared as configurable or non-configurable, block 1102. In this way, a programmer programming a node may make an initial determination as to the state the parameter should normally be set to. For example, the programmer may determine in a typical configuration, a particular network variable should use acknowledged message services. However, the programmer may also allow a network administrator flexibility in configuring and optimizing the network by declaring the acknowledged parameter as configurable. The program is then compiled and a compiled output is produced in the conventional manner. In addition to producing the conventional outputs of a compiler, e.g., object code, the compiler of the present invention produces the above-mentioned BIF file which includes information on the declared network variables such as the state of parameters and whether or not such parameters are configurable, block 1103.

During configuration of the network of the present invention, the state of these configurable parameters may be modified by the network administrator, block 1104. In the above-discussed example, the network administrator may determine the network will be optimally configured if the variable declared as acknowledged is actually configured as

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unacknowledged and repeated. It is worthwhile to again refer to Figure 8(a) which illustrates, in addition to other steps in the connection process, the step of setting parameters for the connection, block 806. The parameters which are settable in this step of the configuration process are those parameters declared as configurable in the network variable declarations. These parameters are displayed on a display screen during the configuration process and may be modified by changing the state of the parameters on the display screen. For example, one of three states may be set to tell the network the type of service to be used for a network variable—unacknowledged, unacknowledged and repeated, and acknowledged. The authentication feature may be set to an on state in which message authentication is used or to an off state in which message authentication is not used. Also, network variable may be set to a priority state or a non-priority state indicating whether messages associated with the variable are to be sent as priority messages or as normal messages.

Declaration and use of Objects

Each node of the present invention comprises its own scheduler, timers, and logical I/O devices. The "C" programming language employed by the present invention provides access to these devices through use of predefined objects; namely, an event scheduler which handles task scheduling for the node, timer objects which provide both millisecond and second timers, and I/O objects which provide for declaration of a number of logical I/O devices. Importantly, once declared a logical link is created between the object name and the

physical device and references may be made to the object name to gain access to the physical device.

Declaration and use of objects will be discussed in greater detail by referring to declaration of I/O objects. Each node of the network of the present invention has a number of built-in electrical interface options for performing input and output. Prior to performing input or output, a program must declare an I/O object which interfaces with one of eleven I/O pins on the node; three serial pins 441 and eight parallel pins 445. The eleven pins are referred to with the reserved pin names: IO_0, IO_1, IO_2, IO_3, IO_4, IO_5, IO_6, IO_7, IO_8, IO_9, and IO_10. The declaration syntax for an I/O object and use of the eleven pins in the present invention is discussed further with reference to Table XI.

It is worthwhile to turn to Figure 12 to discuss this concept in somewhat greater detail. Initially, a program statement is coded to declare an I/O device giving a pin designation, a device type and a device name; when the program is compiled the declaration statement causes declaration of the I/O device, block 1201. Other parameters and the format of the declaration for an I/O device in the preferred embodiment may be found with reference to Table XI. Responsive to declaring the I/O device, the pins are configured to perform the function specified by the device type, block 1202. The device types of the preferred embodiment may be found with reference to Table XI.

This process is further illustrated with reference to the exemplary network variable program of Table V and the associated assembly language code resulting from a compile of the program given in Table XIV. As can be seen with reference to the program source code in Table

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V, two I/O devices are declared, IO_0 as a bit output named MotorCtrl and IO_5 as a pulsecount input named pulseamps.

The specified device name is logically associated with the specified device to perform the designated I/O, block 1204. In this way, a reference may be simply made to the device name to accomplish the designated I/O with necessity of continued reference to specific pins and without need for special coding to implement the desired device types. As can be seen with reference to Table XII, built-in functions are provided to allow communication with the I/O devices. One of the built-in functions may be used to perform the built-in function referring to the desired device name to specify a hardware device, block 1204. The desired I/O is then performed in accordance with the device type specified in the device declaration, block 1205.

Scheduling

Scheduling on a node in the present invention is event driven. When a given condition becomes true, a body of code termed a task associated with that condition is executed. In the preferred embodiment, scheduling is accomplished through "when" statements. The syntax of a when statement of the preferred embodiment is given in Table XIII. An example of a when statement is given below:

```

        when (timer_expires (led_timer))      /* This line is the when
clause */
        {
            io_out (led, OFF);                /* This is the task - turn the led off
*/
        }

```

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In the above example, when the application timer `led_timer` expires, the body of code following the `when` statement is executed (and the LED is turned off). `When` statements provide for execution of a task (the bracketed code) when the condition specified (e.g., the `led_timer` expires) evaluates to true. It is known in the art to provide structures in programming languages which allow for conditional execution of a task when a statement evaluates to true. However, in known systems which include a scheduling statement (a `when` statement or the equivalent), the event which is evaluated is a predefined event. As is noted in Table XIII, the present invention provides for use of predetermined events in scheduling statements. However, as one important aspect of the present invention, events may also be any valid C expression. For example, the following statement may be coded in a system of the present invention:

```
    when (x == 3)                /* This line is the when clause
*/
    {
        io_out (led, OFF);      /* This is the task - turn the led off
*/
    }
```

In this case, whenever the event `x==3` occurs, the LED is turned off. Of course, significantly more complicated C programming statements may be envisioned to define an event. As will be understood by one of ordinary skill in the art, allowing evaluation of any valid language expression to define an event offers significant flexibility over known systems. The present invention further allows for use of multiple `when` statements to be associated with a single task. For example:

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```
        when (powerup)           /* This line is one when clause
*/
        when (reset)             /* This line is another when
clause */
        when (io_changes(io_switch)) /* This line is another when
clause */
        when (x = 3)             /* This line is another when
clause */
        {
            io_out (led, OFF);    /* This is the task - turn the led off
*/
        }
```

In this case, when any of the above events evaluates to true, the task is executed—e.g., the LED is turned off.

Importantly, as one aspect of the present invention, I/O objects may be referred to in an event clause allowing improved ease of programming of the system of the present invention. For example, two methods may be used to determine if an input value is new: (1) the `io_update_occurs` event may be used, referring to the desired device in a when statement or the `io_in` function may be used. The below two programs accomplish the same goal.

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PROGRAM 1

```
IO_5 input pulsecount dev;
when (io_update_occurs (dev))
{
    /* perform the desired function */
}
```

PROGRAM 2

```
stimer t;
IO_5 input pulsecount dev;
when (timer_expires(t))
{ io_in (dev);
  if (input_is_new)
  {
    /* perform the desired function */
  }
}
```

The particular method chosen will depend on the individual case; however, the above is exemplary of the flexibility and ease of use of the system of the present invention.

Further, as an additional feature of the present invention and as is described with reference to Table VIII, the present invention provides for two levels of when clauses, priority when clauses and normal when clauses. Using this feature, it is possible to handle events which must be dealt with on a priority basis.

PERFORMANCE OPTIMIZATIONS PERFORMED

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BY THE BINDER OF THE PREFERRED EMBODIMENT

As was discussed above, when more than two nodes are used in a connection, the nodes may be recognized as a group and a group address may be assigned to the group of nodes.

The preferred embodiment also carries out other performance optimization routines to achieve minimal network traffic with resulting optimized response time. For example, the binder determines optimal protocol service class and addressing allocation at the time of binding variables in order. Illustrative of this, with reference to Figure 3(b), three separate connections are shown, 321-323. Although this represents a typical optimal configuration, these three connections could be combined by the binder into a single group resulting in nodes sometimes receiving messages about network variable updates which are not used by those nodes. In such a configuration, although there are additional messages received by the nodes, no effect is seen by the application running on the node because the network variable messages include a 14-bit network variable identification. Therefore, nodes which have no need for a variable sent to them simply discard and, in the case of acknowledged service, acknowledge the message.

An advantage of grouping many nodes in a single group in the system of the preferred embodiment is that such grouping simplifies tasks for the binder process and further uses only one group address (the preferred embodiment is limited to 255 group addresses per domain).

Further, the binder of the present invention dynamically selects an optimal protocol class of service at the time of binding. This is done by first computing the number of messages it would take to complete a

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transaction on the first using acknowledged service (including the original message and the acknowledgements). (Note that this number is the group size which is known by the network variable binder process at the beginning of the connection process). Second, this number is compared with the repeat count for repeating message. If the repeat count is less than the group size, and none of the programs require acknowledged services (each program allows the config option for its network variables), then the binder dynamically converts the service from acknowledged to unacknowledged repeat. This reduces network traffic, thus improving response time.

Thus, an improved communication network having capability for communication of information between nodes in the network is described.

TABLE I

```

/*****
/**
/** Temperature sensor control program writes an output network variable **/
/** temp_high responsive to changes in temperature sensed by a thermostat **/
/**
/*****

/** I/O Declarations **/
IO_1 input bit temp_in;

/** Network variables declaration **/
network output boolean temp_high;

/** working variables declarations and initializations **/
int on_threshold = 72;
int off_threshold = 68;

/*****
/**
/** Event driven code; update temp_high responsive to changes in temperature **/
/** input to the program by temp_in **/
/**
/*****

when (powerup)
when (reset)
{
    io_change_init (temp_in);
}

when (io_changes(temp_in))
{
    if (temp_in > on_threshold)
        temp_high = true;
    if (temp_in < off_threshold)
        temp_high = false;
}

```

TABLE II

```

/*****
**
** Fan control program reads an input network variable fan_on to control
** turning a fan on and off using output bit fan_active.
**
**
*****/

/** I/O Declarations **/

IO_1 output bit fan_active;

/** Network variables declaration **/

network input boolean fan_on;

/*****
**
** Event driven code; updates fan_active each time a change in state occurs
** for the network variable fan_on
**
**
*****/

when (nv_update_occurs(fan_on))
{
  io_out(fan_active, fan_on);
}

```

TABLE III

```
#####  
#  
# This connection associates the temperature sensor control output variables #  
# (temp_high) to a fan control input variable (fan_on). Specifically, temperature #  
# sensor 1 is connected to fan 1; temperature sensor 2 is connected to fan 1 and #  
# and fan 2; and temperature sensor 3 is connected to fan 2. #  
# #  
#####  
  
@N (temp1_controls)  
temp_sensor_1.temp_high          /** writer **/  
fan_1.fan_on                     /** reader **/  
  
@N (temp2_controls)  
temp_sensor_2.temp_high          /** writer **/  
fan_1.fan_on                     /** reader **/  
fan_2.fan_on                     /** reader **/  
  
@N (temp3_controls)  
temp_sensor_3.temp_high          /** writer **/  
fan_2.fan_on                     /** reader **/
```

TABLE IV

```

#####
#
# This connection associates the temperature sensor control output variables
# (temp_high) to a control cell; the control cell is connected to fan control
# input variable (fan_on). Specifically, temperature sensor 1 is connected to
# control cell 1; temperature sensor 2 is connected to control cell 1 and control
# cell 2; temperature sensor 3 is connected to control cell 2; control cell 1 is
# connected to fan 1; and control cell 2 is connected to fan 2
#
#####
@N (connection_1)
temp_sensor_1.temp_high      /** writer **/
cell_1.temp_high             /** reader **/

@N (connection_2)
temp_sensor_2.temp_high      /** writer **/
cell_1.temp_high             /** reader **/
cell_2.temp_high             /** reader **/

@N (connection_3)
temp_sensor_3.temp_high      /** writer **/
cell_2.temp_high             /** reader **/

@N (connection_4)
cell_1.fan_on                /** writer **/
fan_1.fan_on                 /** reader **/

@N (connection_5)
cell_2.fan_on                /** writer **/
fan_2.fan_on                 /** reader **/

```

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TABLE V

NETWORK VARIABLE PROGRAM EXAMPLE

```

#pragma receive_trans_count 8

/* This example has all the setpoint configuration local to this node. */
/* In this way, generic temperature and pressure sensors can be used */
/* which have no knowledge of the setpoints. They only report new temp */
/* values when the old one changes by a threshold value. Additionally, */
/* the temperature value can be reported to many nodes which can each */
/* use the temperature for their specific function -- even applying */
/* different set points to the temperature value. In the old study, */
/* actual temperature values were not sent on the network. Messages */
/* were sent for above high setpoint, at setpoint & below low setpoint. */
/* Since no temperature values were sent, the messages sent could only */
/* be used by this node -- defeating the value of a networked approach */
/* This division of function in the old study was done to save EEPROM */
/* in this node since storing the setpoints takes EEPROM. */

#define true          1
#define false        0
#define on            true
#define off           false

typedef signed int fahrenheit;
typedef signed int PoundsPerSqln;

struct tempSetpoints
{
    fahrenheit LowSet,
    HighSet;
};

struct pressureSetpoints
{
    PoundsPerSqln LowSet,
    HighSet;
};

/* EEPROM nodal configuration parameters: Minimum time the motor must */
/* remain on, minimum time the motor must remain off. Temperature & */

```

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```

/* pressure setpoints. Location and device type, too!! */
config network input
    signed long int      MinOffTime,
                        MinOnTime;

config network input
    struct tempSetpoints OutletWater,
                        CndnsrHead,
                        CoolAir;

config network input
    struct pressureSetpoints CmprsrInltGas;

#pragma set_id_string "HVACComp"

/* Network variable declarations for temperature & pressure inputs */
/* used to decide when the motor should be turned on and off */
network input fahrenheit      OutletWaterTemp,
                                CndnsrHeadTemp,
                                CoolAirTemp;

network input PoundsPerSqIn    CmprsrGasPrsr;

network input boolean          BuildingCooling;

/* Network variable declarations used to report status to the HVAC */
/* system controller. Reported conditions are: node offline/online, */
/* motor on/off, and motor overloaded/O.K. These conditions are only */
/* reported when they change. */
network output boolean         MotorOn,
                                MotorOverload,
                                AmOnline;

/* Definitions of the Neuron® I/O pins. The previous study used an */
/* onchip AtoD to measure the current that the motor used. This version */
/* uses a $.50 external AtoD to convert current to a number of pulses */
/* over a 1 second interval. These pulses are accumulated via the on */
/* chip timer/counter block to determine the current the motor uses */
IO_0 output bit               MotorCtrl;
IO_5 input pulsecount         PulseAmps;

```



```

/* Timer declarations take no EEPROM space -- they are in RAM */
stimer      MinOffTimer,
            MinOnTimer,
            MotorMeasurementTimer;

/* number of pulses that equal the maximum amount of current the motor
/* can draw. The cheap AtoD gives 0 to 255 pulses per second depending
/* on the analog current value.
const int    CompressorMotorMaxDraw=180,
            MeasurementInterval=10;

int          strikes; /* motor overdraw counter */

/* now for some real code! initialization for reset, powerup and online
/* events. Online means the node received a network management message
/* to go online.
void motor(boolean on_off_flag)
{
    MotorOn = on_off_flag;
    io out(MotorCtrl, on_off_flag);

    if (on_off_flag == on)
        MinOnTimer = MinOnTime;
    else
        MinOffTimer = MinOffTime;
}

void control_action()
{
    if ( AmOnline
        BuildingCooling
        MinOffTimer
        OutletWaterTemp
        CndnsrHeadTemp
        CmprsrGasPrsr
        CoolAirTemp
        )
        {
            motor(on);
        }
    else
        {

```

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```

if ( BuildingCooling == 0           &&
      OutletWaterTemp < OutletWater.LowSet &&
      CndnsrHeadTemp > CndnsrHead.HighSet &&
      CmprsrGasPrsr > CmprsrInltGas.HighSet &&
      CoolAirTemp < CoolAir.LowSet
    )
    {
        motor(off);
    }
)

when (reset)
{
    MotorOn = false;
    MotorOverload = false;
    AmOnline = true;
    motor(off);

    /* initialize all input variables so that other nodes */
    /* don't have to all update this one before this one */
    /* begins operation. */

    OutletWaterTemp = OutletWater.LowSet;
    CndnsrHeadTemp = CndnsrHead.LowSet;
    CoolAirTemp = CoolAir.LowSet;
    CmprsrGasPrsr = CmprsrInltGas.LowSet;

    strikes = 0;

    poll(BuildingCooling); /* ask the controller if AC is on */
}

when (online)
{
    AmOnline = true;
    motor(off);

    /* if the motor was overloaded & and we just came back online */
    /* perhaps someone repaired it */
    MotorOverload = false;
}

```

```

)
when(offline)
{
  AmOnline = false;
  motor(off);
}

when ( nv update occurs )
{
  control action();
}

when ( timer expires(MotorMeasurementTimer) )
{
  MotorMeasurementTimer = MeasurementInterval;

  if ( io_in(PulseAmps) > CompressorMotorMaxDraw )
  {
    if (++strikes >= 3) /* motor is really overloaded */
    {
      motor(off);
      MotorOverload = true;
    }
    else
      strikes = 0;
  }
}

```

Link Memory Usage Statistics:
ROM Usage: User Code & Constant Data 335 bytes

EEPROM Usage: (not necessarily in order of physical layout)

System Data & Parameters	72 bytes
Domain & Address Tables	105 bytes
Network Variable Config Tables	42 bytes
User EEPROM Variables	12 bytes
User Code & Constant Data	0 bytes
Total EEPROM Usage	231 bytes

RAM Usage: (not necessarily in order of physical layout)

System Data & Parameters	549 bytes
Transaction Control Blocks	132 bytes
User Timers & I/O Change Events	12 bytes
Network & Application Buffers	424 bytes
User RAM Variables	9 bytes

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Total RAM Usage	1126 bytes
End of Link Statistics	

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TABLE VI
MESSAGING PROGRAM EXAMPLE

```

#pragma receive_trans_count 8

/* This example has all the setpoint configuration local to this node. */
/* In this way, generic temperature and pressure sensors can be used */
/* which have no knowledge of the setpoints. They only report new temp */
/* values when the old one changes by a threshold value. Additionally, */
/* the temperature value can be reported to many nodes which can each */
/* use the temperature for their specific function -- even applying */
/* different set points to the temperature value. In the old study, */
/* actual temperature values were not sent on the network. Messages */
/* were sent for above high setpoint, at setpoint & below low setpoint. */
/* Since no temperature values were sent, the messages sent could only */
/* be used by this node -- defeating the value of a networked approach */
/* This division of function in the old study was done to save EEPROM */
/* in this node since storing the setpoints takes EEPROM. */

#define true          1
#define false        0
#define on           true
#define off          false

/* Add In some message codes */

#define CondensrTemp    0      /* net in condensor temp */
#define CoolTemp       1      /* net in air temp */
#define GasPress       2      /* net in gas pressure */
#define BldCool        3      /* net in building cooling stat */
#define MotOn          4      /* net out cmprsr mot on */
#define MotOvld       5      /* net out cmprsr mot overload */
#define NdOnline       6      /* net out online */
#define Poll BldCool   7      /* poll building status */
#define TimeMinOff_c   8      /* Config Msg code for time off */
#define TimeMinOn_c   9      /* Config Msg code for time on */
#define OutletH2O     10      /* Net in H2O temperature */
#define CndnsrHd_c    11      /* cndsr head temp config */
#define ColdAir_c     12      /* Cold air temp config */
#define CompGasPress_c 13     /* gass pressure config */
#define OutletH2O_c   14     /* Config Msg code for water tmp */

```

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```

typedef signed int fahrenheit;
typedef signed int PoundsPerSqIn;

struct tempSetpoints
{
    fahrenheit LowSet,
    HighSet;
};

struct pressureSetpoints
{
    PoundsPerSqIn LowSet,
    HighSet;
};

/* EEPROM nodal configuration parameters: Minimum time the motor must
/* remain on, minimum time the motor must remain off. Temperature &
/* pressure setpoints. Location and device type, too!!
*/

signed long int    MinOffTime,
                  MinOnTime;

struct tempSetpoints    OutletWater,
                        CndnsrHead,
                        CoolAir;

struct pressureSetpoints    CmprsrInltGas;

#pragma set_id_string "HVACComp"

/* Network variable declarations for temperature & pressure inputs
/* used to decide when the motor should be turned on and off
*/

fahrenheit    OutletWaterTemp,
              CndnsrHeadTemp,
              CoolAirTemp;

PoundsPerSqIn    CmprsrGasPrsr;

boolean    BuildingCooling;

/* Network variable declarations used to report status to the HVAC
/* system controller. Reported conditions are: node offline/online,
/* motor on/off, and motor overloaded/O.K. These conditions are only
*/

```

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```

/* reported when they change.*/
boolean      MotorOn,
             MotorOverload,
             AmOnline;

/* Definitions of the Neuron® I/O pins. The previous study used an */
/* onchip AtoD to measure the current that the motor used. This version */
/* uses a $.50 external AtoD to convert current to an number of pulses */
/* over a 1 second interval. These pulses are accumulated via the on */
/* chip timer/counter block to determine the current the motor uses */

IO_0 output bit MotorCtrl;
IO_5 input pulsecount PulseAmps;

/* Timer declarations */

timer       MinOffTimer,
            MinOnTimer,
            MotorMeasurementTimer;

/* number of pulses that equal the maximum amount of current the motor */
/* can draw. The cheap AtoD gives 0 to 255 pulses per second depending */
/* on the analog current value.*/

const int   CompressorMotorMaxDraw=180,
            MeasurementInterval=10;

int strikes; /* motor overdraw counter*/

/* Define all the message tags */

msg  tag   air_temp_in;
msg  tag   gas_press_in;
msg  tag   bidstate_in;
msg  tag   motIsOn_out;
msg  tag   motIsOvrid_out;
msg  tag   Im_onln_out;
msg  tag   getBldState;
msg  tag   config_msg;
msg  tag   water_temp_in;
msg  tag   cndsr_temp_in;

/* now for some real code! initialization for reset, powerup and online */
/* events. Online means the node received a network management message */

```

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```

/* to go online. */

void motor(boolean on_off_flag)
{
    MotorOn      = on_off_flag;
    io_out(MotorCtrl, on_off_flag);
    msg_out.tag   = motIsOn_out;
    msg_out.code  = MotOn;
    msg_out.data[0] = MotorOn;
    msg_send();

    if (on_off_flag == on)
        MinOnTimer = MinOnTime;
    else
        MinOffTimer = MinOffTime;
}

void control_action()
{
    if (
        AmOnline           &&
        BuildingCooling   &&
        MinOffTimer == 0   &&
        OutletWaterTemp > OutletWater.HighSet &&
        CndnsrHeadTemp < CndnsrHead.LowSet &&
        CmprsrGasPrsr < CmprsrInltGas.LowSet &&
        CoolAirTemp > CoolAir.HighSet
    )
    {
        motor(on);
    }

    else
    {
        if (
            BuildingCooling           &&
            MinOnTimer == 0           &&
            OutletWaterTemp < OutletWater.LowSet &&
            CndnsrHeadTemp > CndnsrHead.HighSet &&
            CmprsrGasPrsr > CmprsrInltGas.HighSet &&
            CoolAirTemp < CoolAir.LowSet
        )
        {

```


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```

                                motor(off);
                                )
                                )

when (reset)
(
    MotorOn           =           false;
    MotorOverload     =           false;
    AmOnline           =           true;

    msg_out.tag       =           motIsOn_out;
    msg_out.code      =           MotOn;
    msg_out.data[0]   =           MotorOn;
    msg_send();

    msg_out.tag       =           motIsOvrid_out;
    msg_out.code      =           MotOvld;
    msg_out.data[0]   =           MotorOverload;
    msg_send();

    msg_out.tag       =           Im_onln_out;
    msg_out.code      =           NdOnline;

    msg_out.data[0]   =           AmOnline;
    msg_send();

    motor(off);

    /* initialize all input variables so that other nodes */
    /* don't have to all update this one before this one*/
    /* begins operation.*/

    OutletWaterTemp  =           OutletWater.LowSet;
    CndnsrHeadTemp   =           CndnsrHead.LowSet;
    CoolAirTemp       =           CoolAir.LowSet;
    CmprsrGasPrsr     =           Cmprsr-nlLGas-owSet;

    strikes           =           0;

    msg_out.tag       =           getBldState;
    msg_out.code      =           Poll BldCool;
    msg_out.service   =           REQUEST;
    msg_send();

```

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```

)
when(online)
{
    AmOnline          =   true;
    msg_out.tag       =   Im_onln_out;
    msg_out.code      =   NdOnline;
    msg_out.data[0]   =   AmOnline;
    msg_send();
    motor(off);

    /* if the motor was overloaded & and we just came back online */
    /* perhaps someone repaired it*/

    MotorOverload    =   false;
    msg_out.tag       =   motlsOvrid_out;
    msg_out.code      =   MotOvld;
    msg_out.data[0]   =   MotorOverload;
    msg_send();
}

when (offline)
{
    AmOnline          =   false;
    msg_out.tag       =   Im_onln_out;
    msg_out.code      =   NdOnline;
    msg_out.data[0]   =   AmOnline;
    motor(off);
}

when ( msg_arrives(CondensrTemp) )
{
    CndnsrHeadTemp = (msg_in.data[0]<<8) + msg_in.data[1];
    control_action();
}

when(msg_arrives(CoolTemp))
{
    CoolAirTemp =(msg_in.data[0]<<8) + msg_in.data[1];
    control_action();
}

```

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```
when ( msg_arrives(GasPress))
{
    CmprsrGasPrsr = (msg_in.data[0]<<8) + msg_in.data[1];
    control_action();
}

when ( msg_arrives(BldCool))
{
    BuildingCooling = msg_in.data[0];
    control_action();
}

when ( msg_arrives(OutletH2O))
{
    OutletWaterTemp = (msg_in.data[0]<<8) + msg_in.data[1];
    control_action();
}

when ( msg_arrives(TimeMinOff_c))
{
    MinOffTime = (msg_in.data[0]<<8) + msg_in.data[1];
}

when ( msg_arrives(TimeMinOn_c))
{
    MinOnTime = (msg_in.data[0]<<8) + msg_in.data[1];
}

when ( msg_arrives(CndnsrHd_c))
{
    CndnsrHead.LowSet = (msg_in.data[0]<<8) + msg_in.data[1];
    CndnsrHead.HighSet = (msg_in.data[2]<<8) + msg_in.data[3];
}

when ( msg_arrives(ColdAir_c))
{
    CoolAir.LowSet = (msg_in.data[0]<<8) + msg_in.data[1];
    CoolAir.HighSet = (msg_in.data[2]<<8) + msg_in.data[3];
}

when ( msg_arrives(CompGasPress_c))
{
    CmprsrInltGas.LowSet = (msg_in.data[0]<<8) + msg_in.data[1];
    CmprsrInltGas.HighSet = (msg_in.data[2]<<8) + msg_in.data[3];
}
```

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```

    }
when ( msg_arrives(OutletH2O_c))
{
    OutletWater.LowSet = (msg_in.data[0]<<8) + msg_in.data[1];
    OutletWater.HighSet = (msg_in.data[2]<<8) + msg_in.data[3];
}

when ( timer_expires(MotorMeasurementTimer) )
{
    MotorMeasurementTimer = MeasurementInterval;

    if ( io_in(PulseAmps) > CompressorMotorMaxDraw)
    {
        if (++strikes >= 3) /* motor is really overloaded */
        {
            motor(off);
            MotorOverload = true;
            msg_out.tag = motIsOvrid out;
            msg_out.code = MotOvid;
            msg_out.data[0] = MotorOverload;
            msg_send();
        }
    }
    else
        strikes = 0;
}

```

Link Memory Usage Statistics:

ROM Usage: User Code & Constant Data 626 bytes

EEPROM Usage: (not necessarily in order of physical layout)

System Data & Parameters	72 bytes
Domain & Address Tables	105 bytes
Network Variable Config Tables	0 bytes
User EEPROM Variables	0 bytes
User Code & Constant Data	0 bytes
Total EEPROM Usage	177 bytes

RAM Usage: (not necessarily in order of physical layout)

System Data & Parameters	549 bytes
Transaction Control Blocks	132 bytes
User Timers & I/O Change Events	12 bytes
Network & Application Buffers	600 bytes
User RAM Variables	21 bytes
Total RAM Usage	1314 bytes

End of Link Statistics

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TABLE VII
STANDARD NETWORK VARIABLE TYPES

#	Name	Quantity	Units	Range	Bits	Resolution
1	SNVT_amp	current	amps	-3,276 - 3276	16	0.1 ampere
2	SNVT_amp_mil	current	milliAmps	-3,276 - 3276	16	0.1 milliampere
3	SNVT_angle	phase/rotation	radians	0 - 65	16	0.001 radian
4	SNVT_angle_vel	angular velocity	radians/sec	3,276 - 3276	16	0.1 radians/sec
5	SNVT_char_ascii	character	character	0 - 255	8	1 character
6	SNVT_count	count,event	counts	0 - 65,535	16	1 count
7	SNVT_count_inc	incremental counts	counts	-32,768 - +32,767	16	1 count
8	SNVT_date_cal	date	YYYY,MM,DD	1-3000,0-12,0-31,	32	1 day
9	SNVT_date_day	day of Week	Enum list	M,Tu,W,Th,F,Sa,Su	8	N/A
10	SNVT_date_time	time of day	HH:MM:SS	00:00:00 to 23:59:59	24	1 second
11	SNVT_elec_kwh	energy, elec	Kilowatt-Hours	0 - 65,535	16	1 KWH
12	SNVT_elec_whr	energy, elec	watt-hours	0 - 6,553	16	0.1 WHR
13	SNVT_flow_mil	flow	milliliters/sec	0 - 65,535	16	1ml/s
14	SNVT_length	length	meters	0 - 6,553	16	0.1m
15	SNVT_length_kilo	length	kilometers	0 - 6,553	16	0.1km
16	SNVT_length_micr	length	microns	0 - 6,553	16	0.1km
17	SNVT_length_mil	length	millimeters	0 - 6,553	16	0.1mm
18	SNVT_lev_contin	level, contin	percent	0 - 100%	8	.5%
19	SNVT_lev_disc	level, discrete	Enumerated list		8	N/A
20	SNVT_mass	mass	grams	0 - 6,553	16	0.1g
21	SNVT_mass_kilo	mass	kilograms	0 - 6,553	16	0.1kg
22	SNVT_mass_mega	mass	metric tons	0 - 6,553	16	0.1 tone
23	SNVT_mass_mill	mass	milligrams	0 - 6,553	16	0.1mg
24	SNVT_power	power	watts	0 - 6,553	16	0.1 watt
25	SNVT_power_kilo	power	watts	0 - 6,553	16	0.1 kwatt
26	SNVT_ppm	concentration	ppm	0-65,535	16	1ppm
27	SNVT_press	pressure	pascals	-32,768 - 32,767	16	1 pascal
28	SNVT_press_psi	pressure	lbs/sq-in	-3,276 - 3,276	16	0.1 psi
29	SNVT_res	resistance	Ohms	0 - 6,553	16	0.1 Ohm
30	SNVT_res_kilo	resistance	kiloOhms	0 - 6,553	16	0.1 kilo-Ohm
31	SNVT_sound_db	sound Level	dBspl	-327 - 327	16	0.01 dB
32	SNVT_speed	speed	meters/second	0 - 655	16	0.01m/s
33	SNVT_speed_kmh	speed	km/hour	0 - 655	16	0.01 km/h
34	SNVT_state_supr	sensor state	Enumerated list		8	N/A
35	SNVT_str_asc	char string	ASCII characters(s)	30 characters	248	N/A
36	SNVT_str_int	char string	Int'l			

SUBSTITUTE SHEET

#	Name	Quantity	Units	Range	Bits	Resolution
			char set (s)	14 characters	248	N/A
37	SNVT_telecom	phone state	Enumerated list		8	N/A
38	SNVT_temp	temperature	Celsius	-3,276 - +3,276	16	0.1 degree
39	SNVT_time_passed	elapsed time	HH:MM:SS:LL	0 - 65,536	48	0.001 sec
40	SNVT_vol	volume	liters	0 - 6,553	16	0.1 liter
41	SNVT_vol_kilo	volume	kiloliters	0 - 6,553	16	0.1 kiloliter
42	SNVT_vol_mil	volume	milliliters	0 - 6,553	16	0.1 milliliter
43	SNVT_volt	voltage	volts	-3,276 - 3,276	16	0.1 volt
44	SNVT_volt_dbmv	voltage	dB microvolts	-327 - 327	16	0.01 db uv dc
45	SNVT_volt_kilo	voltage	kilo volts	-3,276 - 3,276	16	0.1 kilovolt
46	SNVT_volt_mil	voltage	millivolts	-3,276 - 3,276	16	0.1 millivolt

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TABLE VIII

NETWORK VARIABLE DECLARATION

The preferred syntax for declaration of a network variable is as follows:

network input | output [netvar modifier] [class] type [bind_info (fields)] identifier;

where:

netvar modifier are the following optional modifiers which can be included in the declaration of a network variable:

sync / synchronized — specifies that all values assigned to this network variable must be propagated, and in their original order. However, if a synchronous network variable is updated multiple times within a single critical section, only the last value is sent out. If this keyword is omitted from the declaration, the scheduler does not guarantee that all assigned values will be propagated. For example, if the variable is being modified more rapidly than its update events can be processed, the scheduler may discard some intermediate data values. However, the most recent data value for a network variable will never be discarded.

polled — is used only for output network variables and specifies that the value of the output network variable is to be sent only in response to a poll request from a node which reads the network

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variable. When this keyword is omitted, the value is propagated over the network every time the variable is assigned a value.

class

Certain classes of storage may be specified for network variables. Specifically, the following keywords may be entered in the network variable declaration statement:

const — specifies that the network variable may not be changed by the application program;

eprom — allows the application program to indicate the value of the network variable is to be preserved across power outages. In the preferred embodiment, variables declared with this storage class are stored in the eeprom 401. EEPROM variables have a limited capability to accept changes before the EEPROM can no longer be guaranteed to operate properly. Therefore, initializers for the eeprom class take effect when the program is loaded and not each time the program is started. Reloading a program has the effect of reinitializing all eeprom variables.

config — specifies a const network variable in EEPROM that can be changed only by a network management node. This class of network variable is typically used for application configuration by a network manager.

type	<p>Network variable typing serves two purposes: (1) typing ensures proper use of the variable in the compilation, and (2) typing ensures proper connection of network variables at bind time. Network variables may be declared as any one of the following types:</p> <ul style="list-style-type: none">[signed] long integerunsigned long integersigned character[unsigned] character[signed] [short] integerunsigned [short] integerenumerated listsstructures and unions of the above typesstandard network variable types (see Table VII)
bind_info (fields)	<p>The following optional fields may be included in the declaration of a network variable; the compiler builds the BIF file utilizing information declared in these fields and the information in the BIF file is used for binding the network variable inputs and outputs. The fields are each optional and may be specified in any order.</p> <p><i>offline</i> — is used to signal to the bind process that a node should be taken offline before an update can be made to the network variable.</p>

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This option is commonly used with the config class network variable.

bind | *bind(var_name)* — specifies whether the network variable is bound to network variables on other nodes (the usual case) or to a network variable on the same node. The default is *bind* which indicates that the network variable can be bound to network variables on other nodes. The other form, *bind (var_name)* allows binding an output to an input on the same node. The *var_name* is the name of another network variable on the same node. It should be noted that this option has been omitted from the currently preferred embodiment of the present invention.

unackd | *unackd_rpt* | *ack [(config | nonconfig)]* — tells the protocol layer of the network management software of the present invention the type of service to use for the variable. An unacknowledged (*unackd*) network variable uses minimal network resources to propagate its values to other nodes. As a result, propagation failures are more likely to occur, and such failures are not detected by the node. This class is typically used for variables which are updated on a frequent, periodic basis, where the loss of an update is not critical, or in cases where the probability of a collision or transmission error is extremely low. The *unackd_rpt* class of service is used when a variable is sent to a large group of

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other nodes; with this class the message is sent multiple times to gain a greater probability of delivery. Acknowledged (*ackd*) service provides for receiver node acknowledged delivery with retries. The keyword *config*, indicates the service type can be changed at the time connections are specified for the network variable. The keyword *nonconfig* indicates the service type cannot be changed at configuration time.

authenticated | *nonauthenticated* [(*config* | *nonconfig*)] — specifies whether the network variable requires use of an authentication to verify the identity of the sender node. The *config* | *nonconfig* keywords specify whether the authentication designation is configurable. The default in the system of the preferred embodiment is *nonauth* (*config*).

priority | *nonpriority* [(*config* | *nonconfig*)] — specifies whether the network variable receives priority or not. The keywords *config* | *nonconfig* specify whether priority is configurable. The default is *nonpriority* (*config*).

rate_est (*const_expression*) — specifies the estimated average message rate, in tenths of messages per second, that an associated network variable is expected to transmit or receive. This value assists the network administrator in configuring the network.

max_rate_est (*const_expression*) — specifies the estimated maximum message rate, in tenths of messages per second, that the

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associated network variable is expected to transmit or receive. This value assists the network administrator in configuring the network.

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TABLE IX

BIF FILE FORMAT

The Binder Interface File (BIF) format comprises a number of records—one record per network variable and one record per message tag plus some overhead records. The format is designed to be concise with few lines of physical lines per record. The format of the file generally allows for the following record types: (1) File Header comprising timestamp and other general information (one record); (2) Global information comprising general information of indicating general information about the node and the application program running on the node; and (3) Network variable and message tag records for each network variable and message tag comprising information about the network variable or message tag.

Importantly, network variables and message tags may require differing amounts and formats of information. Therefore, as one aspect of the present invention, a record structure has been developed to allow efficient storage of the differing required information and efficient retrieval of the records. In addition, in order to conserve storage, the present invention discloses an encoding scheme to encode numeric information present in the records.

In general, string fields contain an asterisk if they are not applicable. Integer fields contain a zero. The first record in the file is a header which comprises three lines of commentary and copyright notice text and a timestamp. Following this header is one blank line followed by global information used by the binder process.

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Global Information

The first global value line is a Program ID comprising eight 2-digit hexadecimal values, separated by colons. The second global value line comprises several numeric fields separated by spaces. The fields are defined in order as follows:

- Either a 1 or a 2 which specifies the number of domains.
- The number of address table 901 slots in the range of decimal 1-15.
- Either a 0 or a 1. Indicates whether the node application program handles incoming messages.
- The number of network variables defined by the application program in the range of 0 to 62.
- The number of message tags defined by the application program in the range 0 to 15.
- The number of network input buffers (encoded, see below).
- The number of network output buffers (encoded, see below).
- The number of priority network output buffers (encoded, see below).
- The number of priority application output buffers (encoded, see below).
- The number of application output buffers (encoded, see below).
- The number of application input buffers (encoded, see below).
- The size of a network input buffer (encoded, see below).
- The size of a network output buffer (encoded, see below).
- The size of an application input buffer (encoded, see below).
- The size of an application output buffer (encoded, see below).

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The third line is used for node-specific parameters and has not been fully defined in the currently preferred embodiment. The fourth and following lines are optional and may include a node documentation string which may be transmitted to the network management node for documenting, for example, the general function of the node. If not supplied, these nodes comprise a single asterisk. If supplied, these lines each begin with a double-quote character which is not included as part of the documentation string. Multiple lines are concatenated without any intervening characters. There is no end double quote. The global values section ends with a blank line.

As noted above, buffer sizes and count fields are encoded. The encoded values allow selected values, given below, to be stored in a nibble, thus reducing the size of the database. In the preferred embodiment, buffer sizes must be one of 20, 21, 22, 24, 26, 30, 34, 42, 50, 66, 82, 114, 146, 210 or 255 (i.e., 15 allowed buffer size values where the buffer sizes are given in bytes); non-priority buffer counts must be one of 1, 2, 3, 5, 7, 11, 15, 23, 31, 47, or 63 (i.e., 11 allowed buffer size values). Priority buffer counts must be one of 0, 1, 2, 3, 5, 7, 11, 15, 23, 31, 47, or 63 (i.e., 12 allowed buffer size values).

In order to represent these values in a single nibble (4 bits), the following formulas are used to transform the nibble value (n) to the above values:

for buffer sizes: $2^{n/2} + (n \& 1) * 2^{n/2-1} + 18$ (except where $n = 0$; size = 255); and

for count (priority and non-priority): $2^{n/2} + (n \& 1) * 2^{n/2-1} - 1$

where n is the nibble value and the & symbol indicates a logical AND function between the four bit n value and 0001 (e.g., for $n = 310$, the result of $n \& 1$ is $0011 \& 0001 = 0001$ or 110 , for $n=2$, the result is 010 ; in general for any even number n, the value of this function will be 0 and for any odd number n, the value will be 1). Also, in the above equations, integer arithmetic is used;

therefore, where fractional values result in the computation of a value (e.g., $n/2$ where $n = 1$), the fractional values are rounded down to the next lowest integer (e.g., for $n=1$, $n/2 = 1/2$, is rounded down to 0). Use of the above formula, as opposed to, for example a table lookup routine, leads to decreased requirements for static memory.

Network Variable and Message Tag Records

Zero or more records are produced which correspond to the network variables and message tag definitions in the program. Message tag records begin with the word "TAG"; Network variable messages begin with "VAR". Following the "TAG" or "VAR" identifier is a string of at maximum 16 characters which is the name of the tag or variable. Next, there is a decimal number (0-61 for network variables; 0-14 for message tags) which translates the name into an internal program index for the object code. Finally, there are two rate estimates, each a decimal number from 0-255, which are the `rate_est` and `max_rate_est`, respectively, in units of tenths of a message per second.

The second line of each record corresponds to the `bind_info` fields and other numeric fields in the order and as defined below:

<u>Field</u>	<u>Values</u>
offline specifier	0 or 1
bindable specifier	0 or 1
bind target index	0-61 (63 if no bind target is specified)
direction	0=input, 1=output
service type	0=acknowledged, 1=unackd_rpt, 2=unackd
service type configurable?	1=yes, 0=no

authenticated?	1=yes, 0=no
authenticated configurable?	1=yes, 0=no
priority	1=yes, 0=no
priority configurable?	1=yes, 0=no
polled	1=yes, 0=no
synchronized	1=yes, 0=no
config	1=yes, 0=no

The third and any subsequent lines optionally contain variable documentation in the same format as the node documentation described above. If no documentation is supplied, a single asterisk is used.

For network variables, the remaining lines following any documentation comprise the following information. Message tags do not require this information.

The first line following the documentation lines is a header in which a first field indicates whether the variable is a standard network variable type; if so, the remaining fields are ignored and there are no more lines in the record. The format of the line, in order of the fields, is as follows:

<u>Field</u>	<u>Values</u>
Standard network variable type number	1-255 (0 if not a standard type)
First typedef name used in the definition	maximum length 16 characters, * if none
Number of elements in the type	1 unless structured or union, 256 max

There is one additional line per element, (where the number of elements was given immediately above). The format of these lines is as follows, in order of the fields presented:

<u>Field</u>	<u>Values</u>
--------------	---------------

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Basic Type	0=char, 1=integer, 2=long, 3=bitfield, 4=union
Bitfield Offset	0-7, 0 if not applicable
Bitfield / union size	1-7 for bitfield; 1-31 for union; 0 if not applicable
Signedness	0=unsigned, 1=signed
Array bound	1-31, 0 if not an array

TABLE X

BIF FILE FOR PROGRAM OF TABLE V

```

File: node_31_right.bif generated by APC Revision 0.99
Copyright (c) 1990 Echelon Corporation
Run on Mon Feb 4 10:31:40 1991

48:56:41:43:6F:6D:70:00
2 15014033333311942
*
*

VAR MinOffTime 000
01630010101001
*
0* 1
20010
VAR MinOnTime 100
01630010101001
*
0* 1
20010
VAR OutletWater 200
01630010101001
*
0* 2
10010
10010
VAR CndnsrHead 300
01630010101001
*
0* 2
10010
10010
VAR CoolAir 400
01630010101001
*
0* 2
10010
10010
VAR CmprsrInltGas 500
    
```

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```
01630010101001
*
0* 2
10010
10010
VAR OutletWaterTemp 600
01630010101000
*
0* 1
10010
VAR CndnsrHeadTemp 700
01630010101000
*
0* 1
10010
VAR CoolAirtemp 800
01630010101000
*
0* 1
10010
VAR CmprsrGasPrsr 900
01630010101000
*
0* 1
10010
VAR BuildingCooling 1000
01630010101100
*
0 boolean 1
10010
VAR MotorOn 11000
01631010101000
*
0 boolean 1
10010
VAR MotorOverload 1200
01631010101000
*
0 boolean 1
10010
VAR AmOnline 1300
01631010101000
*
0 boolean 1
10010
```

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TABLE XI
I/O DEVICE DECLARATION

Each I/O device is declared in the application program as an external "device name".
 The syntax for such declaration is as follows:

`<pin> <type> [<assign>] <device-name> [=<initial-output-level>];`

where `<pin>` is one of the eleven reserved pin names: IO_0, IO_1, IO_2, IO_3, IO_4, IO_5, IO_6, IO_7, IO_8, IO_9, and IO_10;

`<type>` is one of the following types, may specify the indicated pins and is subject to the indicated restrictions:

(1) *output bit* — Used to control the logical output state of a single pin, where 0 equals low and 1 equals high; may specify any pin IO_0 to IO_10 and is unrestricted.

(2) *input bit* — Used to read the logical output state of a single pin, where 0 equals low and 1 equals high; may specify any pin IO_0 to IO_10 and is unrestricted.

(3) [*output*] *bitshift* [*numbits* (*<expr>*)] [*clockedge* ({ + / - })] [*kbaud* (*<expr>*)] — Used to shift a data word of up to 16 bits out of the node. Data is clocked out by an internally generated clock. *numbits* specifies the number of bits to be shifted; *clockedge* specifies whether the data is stable on the positive going or negative going edge; and *kbaud* specifies the baud rate. Requires adjacent pin pairs; the pin specification specifies the low numbered pin of the pair and may be IO_0 through IO_6 or IO_8 or IO_9.

(4) *[input] bitshift [numbits (<expr>)] [clockedge ({ + / - })] [kbaud (<expr>)]* —

Used to shift a data word of up to 16 bits into the node. Data is clocked in by an internally generated clock. *numbits* specifies the number of bits to be shifted; *clockedge* specifies whether the data is read on the positive going or negative going edge; and *kbaud* specifies the baud rate. Requires adjacent pin pairs; the pin specification specifies the low numbered pin of the pair and may be IO_0 through IO_6 or IO_8 or IO_9.

(5) *[output] frequency [invert] [clock (<expr>)]* — This device type produces a

repeating square wave output signal whose period is a function of an output value and the selected clock, *clock (<expr>)*, where *clock (<expr>)* specifies one of 8 clocks provided by the node. Must specify IO_0 or IO_1. The mux keyword (see below) must be specified for IO_0 and the ded keyword (see below) must be specified for IO_1.

(6) *[output] triac sync <pin> [invert] [clock (<expr>)]* — This device type is used

to control the delay of an output pulse signal with respect to an input trigger signal, the *sync* input. Must specify IO_0 or IO_1. The mux keyword (see below) must be specified for IO_0 and the ded keyword (see below) must be specified for IO_1. If IO_0 is specified, the sync pin must be IO_4 through IO_7; if IO_1 is specified, the sync pin must be IO_4.

(7) *[output] pulsewidth [invert] [clock (<expr>)]* — This device type is used to

produce a repeating waveform which duty cycle is a function of a specified output value and whose period is a function of a specified clock period. Must specify IO_0 or IO_1. The mux keyword (see below) must be specified for IO_0 and the ded keyword (see below) must be specified for IO_1.

(8) *input pulsecount [invert]* — This device type counts the number of input edges at the input pin over a period of 0.839 seconds. Must specify IO_4 through IO_7.

(9) *output pulsecount [invert] [clock (<expr>)]* — This device type produces a sequence of pulses whose period is a function of the specified clock period. Must specify IO_0 or IO_1. The *max* keyword (see below) must be specified for IO_0 and the *ded* keyword (see below) must be specified for IO_1.

(10) *[input] ontime [invert] [clock (<expr>)]* — This device type measures the high period of an input signal in units of the specified clock period. Must specify IO_4 through IO_7.

(11) *{output / input} serial [baud (<expr>)]* — This device type is used to transfer data using an asynchronous serial data format, as in RS-232 communications. Output serial must specify IO_10; input serial must specify IO_8.

(12) *parallel* — This device type is used to transfer eight bit data words between two nodes across an eleven pin parallel bus. This is a bidirectional interface. Requires all pins and must specify IO_0.

(13) *newswire select <pin> [kbaud (<expr>)]* — This device type is used to transfer data using a synchronous serial data format. Requires three adjacent pins and must specify IO_8. The select pin must be one of IO_0 through IO_7.

(14) *[input] quadrature* — This device type is used to read a shaft or positional encoder input on two adjacent pins. Requires adjacent pin pairs; the pin specification specifies the low numbered pin of the pair and may be IO_0 through IO_6 or IO_8 or IO_9.

(15) *[input] period [invert] [clock (<expr>)]* — This device type measures the total period from negative going edge to negative going edge of an input signal in units of the specified clock period. Must specify IO_4 through IO_7.

(16) *[output] oneshot [invert] [clock (<expr>)]* — This device type produces a single output pulse whose duration is a function of a specified output value and the selected clock value. Must specify IO_0 or IO_1. The mux keyword (see below) must be specified for IO_0 and the ded keyword (see below) must be specified for IO_1.

(17) *[output / input] nibble* — This device type is used to read or control four adjacent pins simultaneously. Requires four adjacent pins; the pin specifies denotes the lowest number pin of the quartet and may be pin IO_0 through IO_4.

(18) *[output / input] byte* — This device type is used to read or control eight pins simultaneously. Requires eight adjacent pins; the pin specification denotes the lowest number pin and must be IO_0.

(In general, pins may appear in a single device declaration only; however, a pin may appear in multiple declarations if the types belong to the set of {bit, nibble and byte});

where <assign> is one of "mux" which indicates the device is assigned to a multiplexed timer counter circuit or "ded" which indicates the device is assigned to a dedicated timer counter circuit; and

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where <initial-output-state> is a constant expression used to set the output pin of the channel to an initial state at initialization time (e.g., when the application program is reset).

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TABLE XII

ACCESS TO I/O DEVICES VIA BUILT IN FUNCTIONS

To access one of the I/O devices (after declaring it as shown above), the application programmer merely calls one of the built-in functions defined below. These built-in functions appear syntactically to be nothing more than procedure calls. However, these procedure calls are not be defined as external functions to be linked in. Instead, these procedure names are "known" to the compiler, and the compiler enforces type checking on the parameters of the procedures.

The built-in function syntax is as follows:

```
<return-value> io_in ( <device> [ <args> ] )
```

```
<return-value> io_out ( <device>, <output-value> [ <args> ] )
```

where the <device> name corresponds to an I/O device declaration and <args> are as follows, depending on the type of device:

bitshift	[, <numbits>]
serial (output only)	, <count>
serial (input only)	, <input-value>, <count>
neurowire (output only)	, <count>
neurowire (input only)	, <input-value>, <count>
parallel (output only)	, <count>

parallel (input only)		, <input-value>, <count>
<p>All other devices do not permit extra arguments in the calls to io_in or io_out.</p> <p>Some of the above arguments may also appear in the device declaration. If the attribute is specified in the declaration and the attribute is supplied as an argument, the argument overrides the declared value for that call only. These attributes may be specified in both places, either place or not at all. If left unspecified, the default is used (see defaults below).</p> <p>The data type of the <return-value> for the function io_in, and the data type of the <output-value> for io_out is given by the following table. The data values will be implicitly converted as necessary. A warning is output by the compiler if an io_in that returns a 16-bit quantity is assigned to a smaller value.</p>		
bit	short	bit 0 used; others are 0
bitshift	long	shifted value
frequency	long	period in nanoseconds
pulsewidth	short	pulsewidth in nanoseconds
pulsecount	long	count in .84 seconds
ontime, period	long	period in nanoseconds
quadrature	short	signed count
oneshot	short	count
nibble	short	bit 0-3 used; others are 0
byte	short	all bits used

For period, pulsecount and ontime input devices, the built-in variable "input_is_new" is set to TRUE whenever the io_in call returns an updated value. The frequency with which updates occur depends on the device declaration

For parallel, serial and neurowire, io_out and io_in require a pointer to the data buffer as the <output-value> and the <input-value>, respectively. For parallel and serial, io_in returns a short integer which contains the count of the actual number of bytes received.

Ranges and defaults

The following ranges and defaults apply to the various IO attributes:

- The bitshift "numbits" may be specified in the bitshift declaration as any number from 1 to 16 and, if not specified, defaults to 16. In the calls to io_in and io_out, the shift value may be any number from 1 to 127. For io_in, only the last 16 bits shifted in will be returned. For io_out, after 16 bits, zeroes are shifted out.
- The bitshift output clock may be either '+' or '-'. It defaults to '+'. This defines whether the data is shifted on the positive-going or negative-going edge of the clock. This can only be specified in the declaration.
- The initial frequencies of the frequency output, triac output, pulsewidth output and pulsecount output are 0.
- The clock value specifies a clock in the range 0...7 where 0 is the fastest clock and 7 is the slowest. The defaults are as follows:

frequency output	0
triac output	7

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pulsewidth output	0
pulsecount output	7
oneshot output	7
ontime input	2
period input	0

The baud rate of serial may be 300, 1200 or 2400 baud with a default of 2400.

- The baud rate for neurowire and bitshift may be 1,10 or 25 kbits/second and defaults to 25 kbits/second.

Example

An example follows—to read a switch attached to pin 1 and light an LED attached to pin 2 when the switch is closed, the following would be coded by the application programmer:

```
IO_1 input bit ch1 switch;
IO_2 output bit led;
if (io_in(switch))
{
    io_out (led, TRUE);
}
```

I/O Multiplexing

The timer counter circuit may be multiplexed among pins 4 to 7. To facilitate this, the following built-in function is provided:

```
io_select (<device>);
```

This function causes the specified device to become the new owner of the timer counter circuit. Any reinitialization of the timer counter circuit is handled by this function. It is under the application's control when the timer counter is connected to which pin. The multiplexed timer counter is initially assigned to the mux device which is declared first.

For example, the application may choose to select a new device after a when change clause has executed for the current connected device. Alternatively, the selection could be done based on a timer, e.g., select a new device every 100 milliseconds.

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TABLE XIII
WHEN STATEMENT SYNTAX

The syntax of a when statement in the system of the preferred embodiment is given below:

[priority] when (event) task

where:

priority

is an option used to force evaluation of the following when clause each time the scheduler runs. This allows priority when clauses to be evaluated first. Within a program having multiple priority when clauses, priority when clauses are evaluated in the order coded in the program. If any priority when clause evaluates to true, the corresponding task is run and the scheduler starts over at the top of the priority when clauses. If no priority when clause evaluates to true then a non-priority when clause is evaluated and selected in a round robin fashion. The scheduler then starts over with the priority when clauses. This process may be best understood by example: Assume the following when clauses coded in the following order:

priority when (A)

priority when (B)

when (C)

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when (D).

Assume only C and D are true; first A is evaluated, then B is evaluated and finally C is evaluated and the task associated with C is executed. A is then evaluated again, then B is evaluated and then, in round robin fashion, D is evaluated and executed.

event may be either a predefined event or, importantly, may be any valid C expression. Predefined events include, by way of example, input pin state changes (io changes, io update occurs); network variable changes (network variable update completes, network variable update fails, network variable update occurs, network variable update succeeds); timer expiration; message reception information (message arrives, message completes, message fails, message succeeds); and other status information (powerup, reset, online, offline).

task is a C compound statement consisting of a series of C declarations and statements enclosed in braces.

The following predefined events exist in the system of the preferred embodiment:

flush_completes A flush function is available in the system of the preferred embodiment which causes the node to monitor the status of all incoming and outgoing messages. When the node has completed processing of all messages the flush_complete event

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	becomes true indicating all outgoing transactions have been completed, no more incoming messages are outstanding, and no network variable updates are occurring.
io_changes	This event indicates the status of one or more I/O pins associated with a specified input device have changed state.
io_update_occurs	This event indicates that a timer/counter device associated with a specified pin has been updated.
msg_arrives	This event indicates a message has arrived for processing.
msg_completes	This event indicates a message has completed (either successfully or by failure).
msg_fails	This event indicates a message has failed.
msg_succeeds	This event indicates a message has completed successfully.
nv_update_completes	This event indicates a network variable update has completed (either successfully or by failure).
nv_update_fails	This event indicates a network variable update has failed.
nv_update_occurs	This event indicates a network variable update has occurred.
nv_update_succeeds	This event indicates a network variable update has completed successfully.
offline	This event indicates the node has been taken offline.
online	This event indicates the node has been brought online.
powerup	This event indicates the node has been powered up.
reset	This event indicates the node has been reset.
resp_arrives	This event indicates a response has arrived to a message.

timer_expires This event indicates the designated timer has expired.

Predefined events may be used within other control expressions in addition to in the when statement; for example, in an if, while or for statement.

As noted above, a user-defined event may be any valid C expression and may include assignment statements to assign values to global variables and function calls.

TABLE XIV
ASSEMBLY LANGUAGE LISTING FOR THE
NETWORK VARIABLE PROGRAM OF TABLE V

```

; APC - Echelon (R) Neuron (R) Application-C Compiler
; Copyright (c) 1990, Echelon Corporation
; Assembly code from APC Revision 0.99
; Code generated from 'node_31_right.nc' on Mon Feb 4 10:31:40 1991

SUBHEAD Generated from the input file: node_31_right.nc

RADIX HEX

SEG EECODE.
ORG 0F000
NBMTS EQU 000
NNVS EQU 00E
PROTECT EQU 00

NEURONID
RES 8
DIRECTORY
data.b PTR TEVT-3*NNVS,PROTECT+NNVS,0,0
PROGID
data.b 048,056,041,043,06F,06D,070,000
MODETABLE
data.b 053
data.b 0F0,037
data.b 024,09B
data.b 033,033,033
EENEARBYTES
data.b 000
data.b 000,000
data.b 001,000,000,047
LOCATION
RES 8
COMM
RES 10
MSG
RES 1
DOMAIN
    
```

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```

RES      01E
ADDR
RES      04B
TNVCNFG
RES      3 *NNVS
CONFIGCHECKSUM
RES      1
PAGE
; Boilerplate file for compiler-generated assembly output
; Copyright (c) 1990, 1991 Echelon Corporation. All Rights Reserved.
; Date last modified: 1/30/91
; List of exported symbols
EXPORT APINT,DOMAIN,EENEARBYTES,MODETABLE,TEVT
; List of imported symbols - Library functions
IMPORT   application _ restart,delay,error log
IMPORT   flush,flush _ cancel,flush _ wait,go _ offline,go _ unconfigured
IMPORT   node _ reset,offline _ confirm, _ post events,powerup
IMPORT   random,retrieve _ status,retrieve _ xcvr _ status
IMPORT   reverse,timers _ off,watchdog _ update
; List of imported symbols - Compiler helper functions
IMPORT   _abs8,_abs16,_add16,_and16,_alloc
IMPORT   _bcd2bin,_bin2bcd,_dealloc
IMPORT   _div8,_div8s,_div16,_div16s
IMPORT   _drop_n,_drop_n _ preserve_1,_drop_n _ preserve_2
IMPORT   _drop_n _ return_1,_drop_n _ return_2
IMPORT   _eeprom_write,_eeprom _ write _ long
IMPORT   _eeprom_far_write,_eeprom_far _ write _ long
IMPORT   _equal8,_equal16
IMPORT   _gequ8,_gequ8s,_gequ16,_gequ16s
IMPORT   _less8,_less8s,_less16,_less16s
IMPORT   _log8,_log16,_lognot8,_lognot16
IMPORT   _l_shift8,_l_shift8s,_l_shift16,_l_shift16s
IMPORT   _l_shift8_3,_l_shift8_4,_l_shift8_5,_l_shift8_6,_l_shift8_7
IMPORT   _max8,_max8s,_max16,_max16s
IMPORT   _memcpy,_memcpyl,_memset,_memsetl
IMPORT   _min8,_min8s,_min16,_min16s
IMPORT   _minus_16_s
IMPORT   _mod8,_mod8s,_mod16,_mod16s,_mul8,_mul16
IMPORT   _not16,_or16
IMPORT   _pop,_push
IMPORT   _r_shift8,_r_shift8s,_r_shift16,_r_shift16s
IMPORT   _r_shift8_3,_r_shift8_4,_r_shift8_5,_r_shift8_6,_r_shift8_7
IMPORT   _register_call,_sign_extend16
IMPORT   _sub16,_xor16
PAGE

```

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```

; List of imported symbols - I/O functions
IMPORT    _bit_input_ _bit_input_d_ _bit_output
IMPORT    _bitshift_input_ _bitshift_output
IMPORT    _byte_input_ _byte_output
IMPORT    _nibble_input_ _nibble_input_d_ _nibble_output
IMPORT    _frequency_output_ _leveldetect_input
IMPORT    _neurowire_input_ _neurowire_output
IMPORT    _oneshot_output_ _ontime_input
IMPORT    _parallel_input_ _parallel_input_ready
IMPORT    _parallel_output_ _parallel_output_ready_ _parallel_output_request
IMPORT    _period_input
IMPORT    _pulsecount_input_ _pulsecount_output
IMPORT    _pulsewidth_output
IMPORT    _quadrature_input
IMPORT    _serial_input_ _serial_output
IMPORT    _totalize_input_ _triac_output_ _triggered_count_output
IMPORT    _init_timer_counter1_ _init_timer_counter2
IMPORT    _init_baud_ _io_set_clock
IMPORT    _io_input_value_ _io_change_init_ _select_input_fn

list of imported symbols - Messaging support
IMPORT    _bound_mt
IMPORT    _msg_alloc_ _msg_alloc_priority_ _msg_cancel_ _msg_free
IMPORT    _msg_receive_ _msg_send
IMPORT    _msg_addr_blockget_ _msg_addr_get_ _msg_auth_get_ _msg_code_get
IMPORT    _msg_data_blockget_ _msg_data_get_ _msg_len_get_ _msg_service_get
IMPORT    _msg_addr_blockset_ _msg_addr_set_ _msg_auth_set_ _msg_code_set
IMPORT    _msg_data_blockset_ _msg_data_set_ _msg_domain_set_ _msg_node_set
IMPORT    _msg_priority_set_ _msg_service_set_ _msg_tag_set
IMPORT    _resp_alloc_ _resp_cancel_ _resp_free_ _resp_receive_ _resp_send
IMPORT    _resp_code_set_ _resp_data_blockset_ _resp_data_set

; List of imported symbols - Network Variable support
IMPORT    _bound_nv_ _nv_poll_ _nv_poll_all
IMPORT    _nv_update_ _nv_update_int_ _nv_update_long
IMPORT    _nv_update_int_offset_ _nv_update_long_offset

; List of imported symbols - Timer support
IMPORT    _timer_get_ _timer_off
IMPORT    _timer_mset_ _timer_mset_repeat_ _timer_sset_ _timer_sset_repeat

; List of imported symbols - Event support
IMPORT    _flush_completes
IMPORT    _io_changes_ _io_changes_to_ _io_changes_by_ _io_update_occurs
IMPORT    _msg_arrives_ _msg_code_arrives
IMPORT    _msg_completes_ _msg_fails_ _msg_succeeds
IMPORT    _nv_update_completes_ _nv_update_fails_ _nv_update_succeeds
IMPORT    _nv_update_occurs

```

```

IMPORT    _offline, _online, resp, arrives
IMPORT    _timer_expires, timer_expires, any, wink
; List of imported symbols - Misc builtin function support
IMPORT    _sleep
; End boilerplate file

PAGE

      SEG      ENEAR
      ORG      CONSTRAINED
%MinOffTime
      RES      02
      EXPORT   %MinOffTime

      SEG      EENEAR
      ORG      CONSTRAINED
%MinOnTime
      RES      02
      EXPORT   %MinOnTime

      SEG      EENEAR
      ORG      CONSTRAINED
%OutletWater
      RES      02
      EXPORT   %OutletWater

      SEG      EENEAR
      ORG      CONSTRAINED
%CndnsrHead
      RES      02
      EXPORT   %CndnsrHead

      SEG      EENEAR
      ORG      CONSTRAINED
%CoolAir
      RES      02
      EXPORT   %CoolAir

      SEG      EENEAR
      ORG      CONSTRAINED
%CmprsrInltGas
      RES      02
      EXPORT   %CmprsrInltGas

      SEG      RAMNEAR
    
```

ORG	CONSTRAINED
%OutletWaterTemp	
RES	01
EXPORT	%OutletWaterTemp
SEG	RAMNEAR
ORG	CONSTRAINED
%CndnsrHeadTemp	
RES	01
EXPORT	%CndnsrHeadTemp
SEG	RAMNEAR
ORG	CONSTRAINED
%CoolAirTemp	
RES	01
EXPORT	%CoolAirTemp
SEG	RAMNEAR
ORG	CONSTRAINED
%CmprsrGasPrsr	
RES	01
EXPORT	%CmprsrGasPrsr
SEG	RAMNEAR
ORG	CONSTRAINED
RES	01
EXPORT	%BuildingCooling
SEG	RAMNEAR
ORG	CONSTRAINED
%MotorOn	
RES	01
EXPORT	%MotorOn
SEG	RAMNEAR
ORG	CONSTRAINED
%MotorOverload	
RES	01
EXPORT	%MotorOverload
SEG	RAMNEAR
ORG	CONSTRAINED
%AmOnline	

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```

RES      01
EXPORT  %AmOnline

SEC      RAMNEAR
ORG

% strikes
RES      01
EXPORT  %strikes

SEG      CODE
ORG
EXPORT  %motor

%motor ; Function body
push     tos
push     #0B
call     _nv_update_int
push     tos
pushs    #00
call     _bit_output
pushs    01
push     next
call     _equal8
sbrnz   *+4
brf     %motor+01D
push     %MinOnTime
push     %MinOnTime+01
pushs    #01
call     _timer_sset
brf     %motor+026
push     %MinOffTime
push     %MinOffTime+01
pushs    #00
call     _timer_sset
dealloc #01

SEG      CODE
ORG
EXPORT  %control action

%control_action ; Function body
push     [ 1 ][@NEAR (%CoolAirTemp)]
push     %CoolAir+1
call     _less8s
push     %CmprsrInltGas

```

```

push      [1][@NEAR(CmprsrGasPrsr)]
call     _less8s
push     %CndnsrHead
push     [1] [ @ NEAR ( %CndnsrHeadTemp)]
push     [1] [ @NEAR (%OutletWaterTemp)]
push     %OutletWater+01
call     _less8s
pushs   #00
pushs   #00
pushs   #00
call     _timer_get
call     _equal16
push     [1] [ @NEAR(%BuildingCooling)]
push     [1] [ @NEAR( %AmOnline) ]
and
and
and
and
and
and
sbrnz   *+4
brf     %control_action+038
pushs   #01
callf   %motor
brf     %control_action+06A
push    %CoolAir
push    [1] [ @NEAR (%CoolAirTemp) ]
call   _less8s
push   [1] [ @NEAR (%CmprsrGasPrsr) ]
push   %CmprsrInltGas+01
call   _less8
push   [1][@NEAR(%CndnsrHeadTemp)]
push   %CndnsrHead+01
call   _less8s
push   %OutletWater
push   [1][@NEAR(%OutletWaterTemp)]
call   _less8s
pushs  #00
pushs  #00
pushs  #01
call   _timer_get
call   _equal16
push   [1][@NEAR(%BuildingCooling)]
and
and

```

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```

and
and
and
sbrnz      *+4
brf        %control_action+06A
pushs     #00
callf     %motor
ret

SEG        CODE
ORG

WHEN1
EXPORT    WHEN1
callf     %control_action
ret

SEG        CODE
ORG

WHEN2
EXPORT    WHEN2
push      #0A
call      _sign_extend16
pushs    #02
call      _timer_sset
push     #040
call     _pulsecount_input
push     #0B4
call     _sign_extend16
call     _less16
sbrnz   *+4
brf     WHEN2+02E
pushs  #03
push   [1][@NEAR(%strikes)]
inc
push   tog
pop    [1][@NEAR(%strikes)]
call  _gequ8s
sbrnz *+4
brf   WHEN2+02B
pushs #00
callf %motor
push  #01
push  #0C
call  _nv_update_int
brf   WHEN2+031

```

```

pushs      #00
pop        [1][@NEAR(%strikes)]
ret

      SEG      CODE
      ORG
APINIT : Init & event code
push      #084
push      #072
call      _init_timer_counter1
ret
EXPORT    RESET
RESET ; When-unit body
pushs     #00
push      #0B
call      _nv_update_int
pushs     #00
push      #0C
call      _nv_update_int
pushs     #01
push      #0D
call      _nv_update_int
pushs     #00
callf     %motor
push      %OutletWater
pop       [1][@NEAR(%OutletWaterTemp)]
push      %CndnsrHead
pop       [1][@NEAR(%CndnsrHeadTemp) ]
push      %CoolAir
pop       [1][@NEAR(%CoolAirTemp) ]
push      %CmprsrInltGas
pop       [1][@NEAR ( %CmprsrGasPrsr) ]
pushs     #00
pop       [1][@NEAR(%strikes)]
push      #0A
call      _nv_poll
ret
EXPORT    OFFLINE
OFFLINE; When-unit body
pushs     #00
push      #0D
call      _nv_update_int
pushs     #00
callf     %motor
ret
    
```

```

EXPORT      ONLINE

ONLINE ; When-unit body
  pushs     #01
  push      #0D
  call      _nv_update_int
  pushs     #00
  callf     %motor
  pushs     #00
  push      #0C
  call      _nv_update_int
  ret

SEG         CODE
ORG

TNVFX ; NV Fixed table
  data.b    022,PTR %MinOffTime
  data.b    022,PTR %MinOnTime
  data.b    022,PTR %OutletWater
  data.b    022,PTR %CndnsrHead
  data.b    022,PTR %CoolAir
  data.b    022,PTR %CmprsrInltGas
  data.b    021,PTR %OutletWaterTemp
  data.b    021,PTR %CndnrHeadTemp
  data.b    021,PTR %CoolAirTemp
  data.b    021,PTR %CmprsrGasPrsr
  data.b    021,PTR %BuildingCooling
  data.b    021,PTR %MotorOn
  data.b    021,PTR %MotorOverload
  data.b    021,PTR %AmOnline

TEVT ; Event table
  data.b    PTR APINIT-2
  data.b    0,RESET-APINIT+1
  data.b    OFFLINE-APINIT+1,ONLINE-APINIT+1
  data.b    00,02
  data.b    OFF,PTR WHEN1-1
  data.b    0A,PTR WHEN2-1

; Resource usage information
RESOURCE NADDR 0F
RESOURCE NDOM 2
RESOURCE NRCVTX 08
RESOURCE NTMR 03
RESOURCE NNIB 02
    
```

RESOURCE	NNOB	02
RESOURCE	NAIB	02
RESOURCE	NAOB	02
RESOURCE	NNPOB	02
RESOURCE	NAPOB	02
RESOURCE	SNIB	042
RESOURCE	SNOB	02A
RESOURCE	SAIB	016
RESOURCE	SAOB	014
RESOURCE	NNVS	0E

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TABLE XV

GENERAL DEFINITIONS

The following definitions are generally applicable to terms used in this specification:

Neuron, or node: A neuron or node is an intelligent, programmable element or elements providing remote control, sensing, and/or communications, that when interconnected with other like elements forms a communications, control and/or sensing network. Nodes are named with Neuron ids (see below). Nodes may be addressed as a part of a domain and subnet using a node number. The node number in the preferred embodiment is 7 bits. Multiple nodes may be addressed using a group id. The group id in the preferred embodiment is 8 bits.

Neuron id: Nodes in the present invention are assigned a unique identification number at the time of manufacture. The identification number is preferably 48-bits long. This 48-bit identification number does not change during the lifetime of node. As is appreciated, the assignment of a unique identification to each individual node allows for numerous advantages. This 48-bit identification number may be referred to as the `node_id`.

Domain addresses: The term "domain" is used to describe a virtual network wherein all communication, as supported by the network of the present invention, must be within a single domain. Any required inter-domain communication must be facilitated by application level gateways. In the preferred embodiment, domains are identified with 48-bit domain identifiers. However, in certain applications the size of the domain field may vary.

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Subnet — In the preferred embodiment, a subnet is a subset of a domain containing from 0 to 127 nodes. In the preferred embodiment, subnets are identified with an 8-bit subnet identification number. A single domain may contain up to 255 subnets.

Group: A group is a set of nodes which work together to perform a common function. In the preferred embodiment, groups are identified with an 8-bit group identification number. A single domain may contain up to 255 groups. For example, a group may be created to include all nodes in a connection, such as connection_2 142 in which case the group would include a node at temperature sensor_2 116, a node at cell_1 101 and a node at cell_2 121.

Addressing — The present invention provides for a hierarchical address structure and supports three basic addressing modes: (1) (Domain, Subnet, Node number); (2) (Domain, Subnet, Node_id); and (3) (Domain, Group).

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CLAIMS

What is claimed is:

1. A network for communicating information, said network comprising at least a first node and a second, said first node comprising:
 - (a) first data storage means for storing a variable V;
 - (b) first processing means coupled with said first data storage means, said first processing means for writing said first storage location with a new value A, said processing means further for assembling a communication packet for transmission on said network, said communication packet comprising said new value A;
 - (c) first communication means coupled with said first processing means, said first communication means further coupled with a medium, said first communication means for receiving said communication packet from said first processing means and for communicating said communication packet onto said medium;said second node comprising:
 - (d) second data storage means for storing said variable V;
 - (e) second communication means coupled with said medium for receiving said communication packet on said medium;
 - (f) second processing means coupled with said second communication means for receiving said communication packet from said second communication means, said second processing means further coupled with said second data storage means, said second processing means writing said

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second data storage means with said new value A responsive to receiving said communication packet.

2. The network as recited by claim 1 wherein said communication packet further comprises identification information identifying said new value A as being associated with said variable V.
3. The network as recited by claim 1 wherein said identification information is a network variable id comprising 14 bits of information.
4. The network as recited by claim 1 wherein said first node further comprises an address table for storing addressing information of said second node.
5. The network as recited by claim 4 wherein said first node further comprises a network variable table comprising identification information for identifying said variable V and address table index information corresponding to said identification information for indexing said address table.
6. A method of providing shared data from a first node of a network to a second node of said network comprising the steps of:
 - a) declaring a first node W as a writer of a variable V;
 - b) declaring a second node R as a reader of said variable V;

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- c) providing first storage S1 on said first node W for storage of said variable V;
 - d) providing second storage S2 on said second node R for storage of variable V;
 - e) said first node modifying said first storage S1;
 - f) said first node W transmitting a message on said network responsive to modifying said storage S1, said message comprising a new value for said variable V;
 - g) said second node R receiving said message; and
 - h) said second node modifying said second storage S2 responsive to receiving said message.
7. The method as recited by claim 6 wherein said message further comprises identifying information for identifying said variable V.
8. The method as recited by claim 6 further comprising the step of declaring a type of communication service for said message wherein said type of communication service may be declared as configurable.
9. The method as recited by claim 6 further comprising the step of declaring an authentication parameter for said message wherein said authentication parameter may be declared as configurable.
10. The method as recited by claim 6 further comprising the step of declaring a priority parameter for said message wherein said priority parameter may be declared as configurable.

11. A method for providing communication between a first node and a second node in a network, said first node coupled in communication with said second node through a medium, said first node comprising a first processor for processing a first process, a first memory for storing a first network variable, said first process writing said first network variable to said first memory, and a first communication port for communicating information onto said medium, said second node comprising a second processor for processing a second process, a second memory for storing a second network variable, said second process reading said second network variable from said second memory, and a second communication port for receiving information from said medium, said method comprising the steps of:

- (a) programming said first node with said first process;
- (b) programming said second node with said second process;
- (c) logically connecting first network variable with said second network variable by defining a relationship between said first node and said second node; and
- (d) binding said first network variable with said second network variable.

12. The method as recited by claim 11 wherein said step of logically connecting said first network variable with said second network variable comprises the steps of:

- (a) defining a connection name, said connection name for identifying said connection;

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- (b) selecting said first node from a list of nodes;
 - (c) selecting said first network variable from a first list of network variables;
 - (d) selecting said second node from said list of nodes;
 - (e) selecting said second network variable from a second list of network variables;
 - (f) said steps (a) - (e) defining a connection; and
 - (g) adding said connection to a set of connections.
13. The method as recited by claim 11 wherein said step of binding said first network variable with said second network variable comprises the steps of:
- (a) performing edit checks on said logical connection;
 - (b) assigning identification information to said connection, said identification information uniquely identifying said connection to said first node and said second node; and
 - (c) determining an addressing mode for messages associated with said connection.
14. The method as recited by claim 13 wherein said addressing mode is determined to a group addressing mode and said method further comprises the step of assigning a group address to said connection.
15. The method as recited by claim 13 further comprising the step of storing said identification information in a network variable table

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subsequent to assigning said identification information to said connection.

16. The method as recited by claim 13 further comprising the step of storing address information in an address table subsequent to determining said addressing mode.
17. A network of nodes for communicating, controlling and sensing information, said network comprising a first node and a second node, said first node and said second node coupled in communication over a communication medium, said first node comprising:
 - (a) an internal communication bus for communicating information;
 - (b) storage means for storing at least information on a first variable, said storage means coupled in communication with said internal communication bus;
 - (c) interface means coupled in communication with said medium for receiving a first command and for providing said first command to a processing means, said interface means further coupled in communication with said internal communication bus for receiving said information on said first variable and for outputting said information on said first variable on said medium responsive to receiving said information on said first variable; and
 - (d) said processing means for processing information, said processing means coupled in communication with said internal communication bus to receive said first command and

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to communicate a request to read said first variable to said storage means responsive to receiving said first command, said information on said first variable being communicated to said interface means for communication on said medium.

18. The network as recited by claim 17 wherein said information on said first variable comprises variable type information and variable identifying information.
19. The network as recited by claim 18 wherein said variable type information is one of a set of standard variable types defined for said network.
20. A method for configuring nodes of a network, said network comprising a first node and a second node, said first node and said second node coupled in communication with a medium, said first node comprising first storage for storing a first variable, said method comprising the steps of:
 - (a) a network management node communicating a first command to said first node on said medium, said first command requesting said first node communicate configuration information to said network management node;
 - (b) said first node receiving said first command;
 - (c) said first node communicating configuration information regarding said first variable responsive to receiving said first command; and

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- (d) said network management node providing for configuration of said network to allow communication of said first variable between said first node and said second node.
21. The method as recited by claim 20 wherein said configuration information on said first variable comprises variable type information.
22. The method as recited by claim 21 wherein said variable type information is one of a set of standard variable types defined for said network.
23. A method for configuring a network, said network comprising a first node having first storage for storing a first variable of a first type, said first node further having a first processor for manipulating said first variable, said first node further having a first interface for interfacing with a medium to allow a data item stored as said first variable to be communicated onto said medium subsequent to manipulation, said network further comprising a second node having second storage for storing a second variable of said first type, said second node further having a second interface for interfacing with said medium to allow receiving of said data item, said second node further having a processor for storing said data item in said second storage, said method comprising the steps of:
- (a) a network management node communicating a first command to said first node on said medium, said first

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- command requesting said first node communicate configuration information to said network management node;
- (b) said first node receiving said first command and communicating configuration information regarding said first variable to said network management node;
- (c) said network management node communicating a second command to said second node on said medium, said second command requesting said second node communicate configuration information to said network management node;
- (d) said second node receiving said second command and communicating configuration data regarding said second variable to said network management node;
- (e) defining a relationship between said first variable and said second variable;
- (f) communicating network address information of said second node to said first node responsive to defining said relationship, said first node storing said address information associated with said first variable.

24. In a networked communication system comprising at least a first node, a second node and a network management node, said network management node comprising data storage for storing data information including a list of data types, a method of configuring said networked communication system comprising the steps of:

- (a) said network management node communicating a command to said first node requesting said first node to

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respond by transmitting a list of data items used by said first node;

- (b) said first node receiving said command;
- (c) said first node transmitting said list of data items used by said first node responsive to receiving said command, said list comprising information identifying a data type of each of said data items in said list.

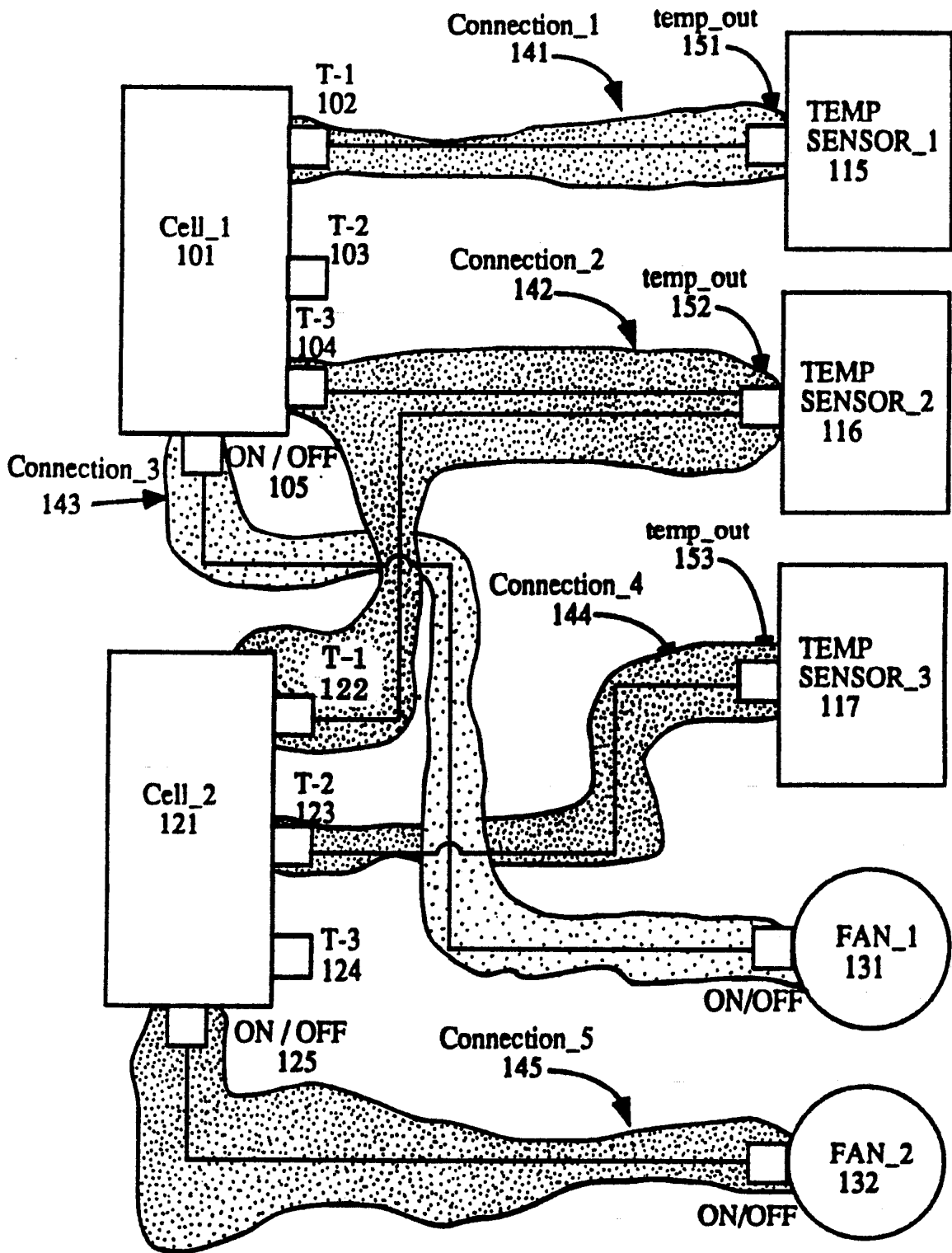


FIG. 1

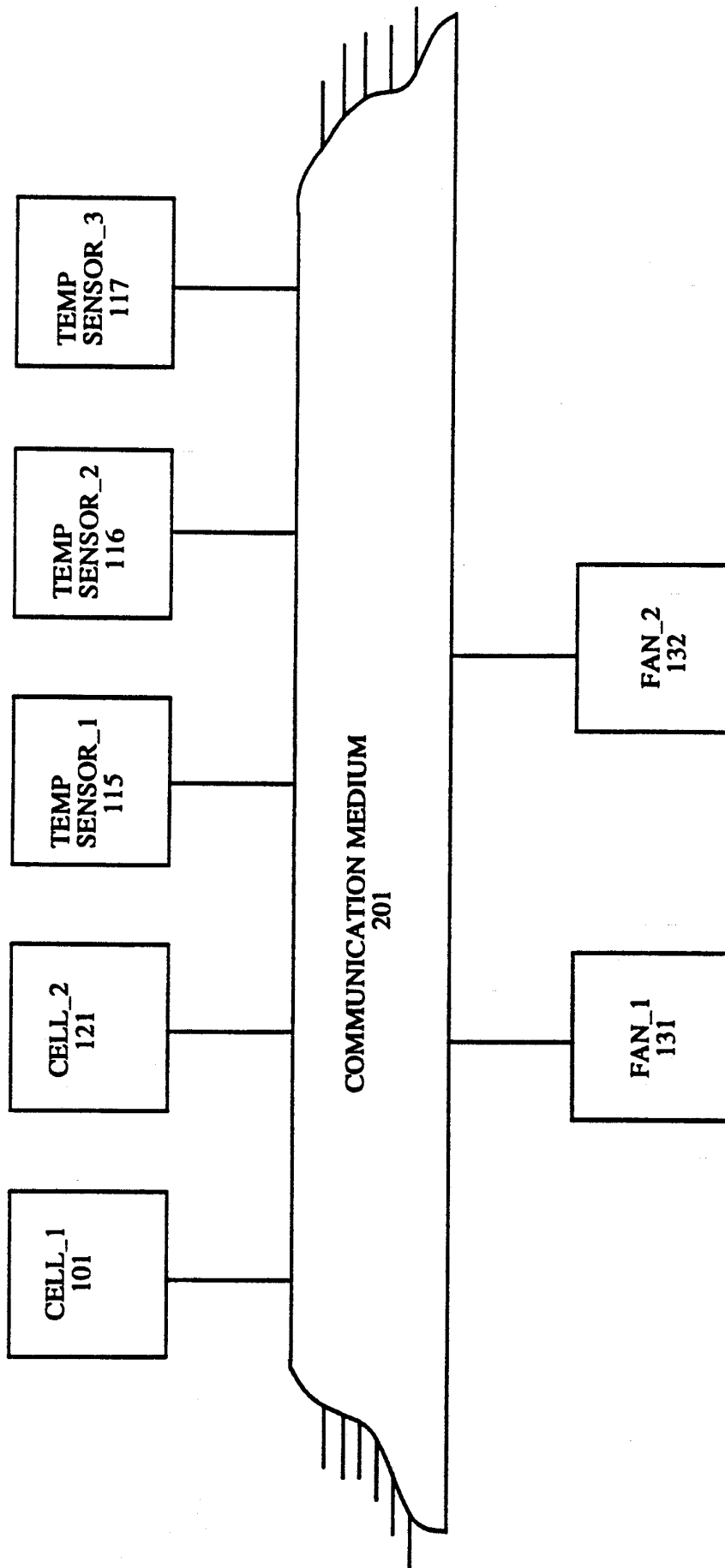


FIG. 2

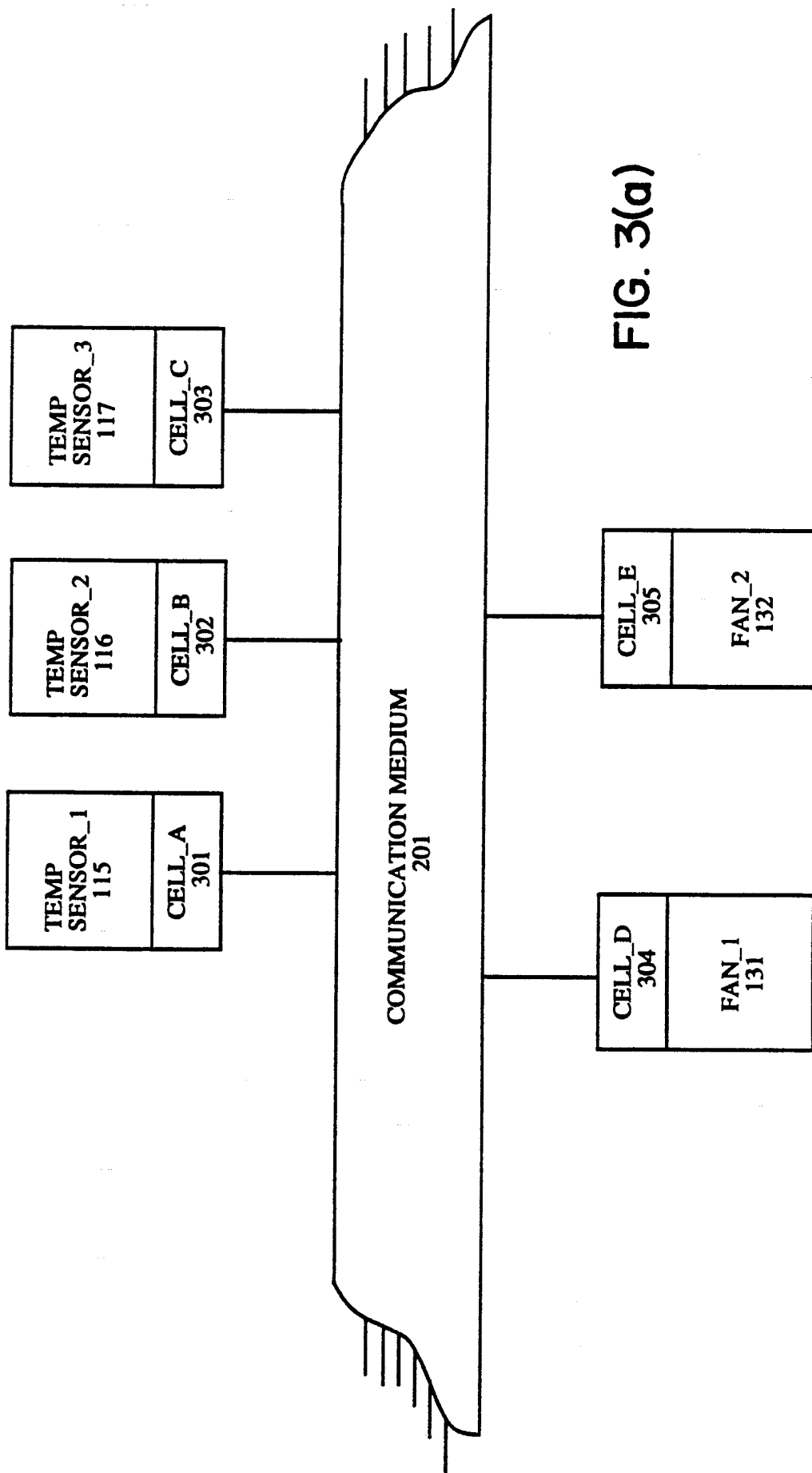


FIG. 3(a)

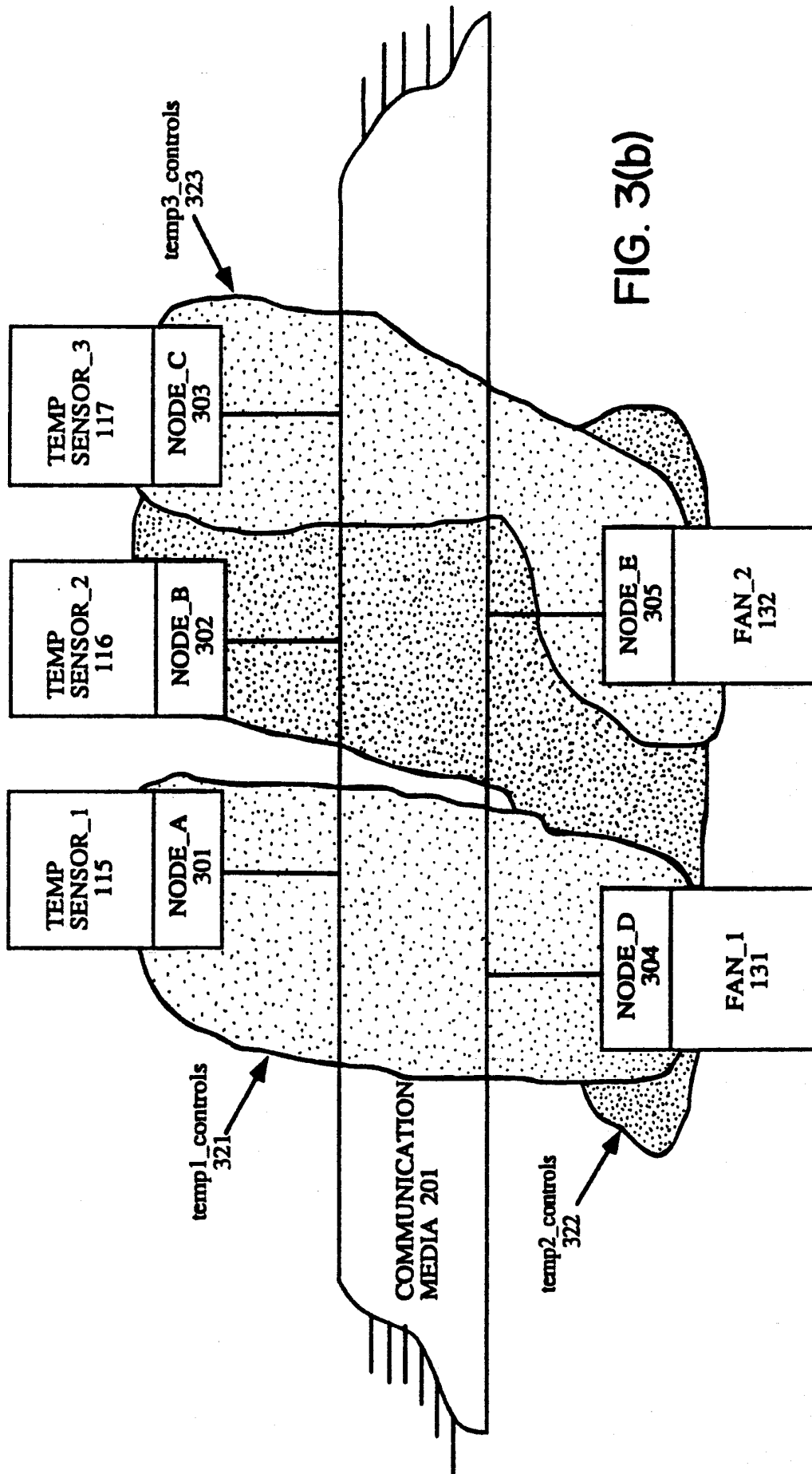


FIG. 3(b)

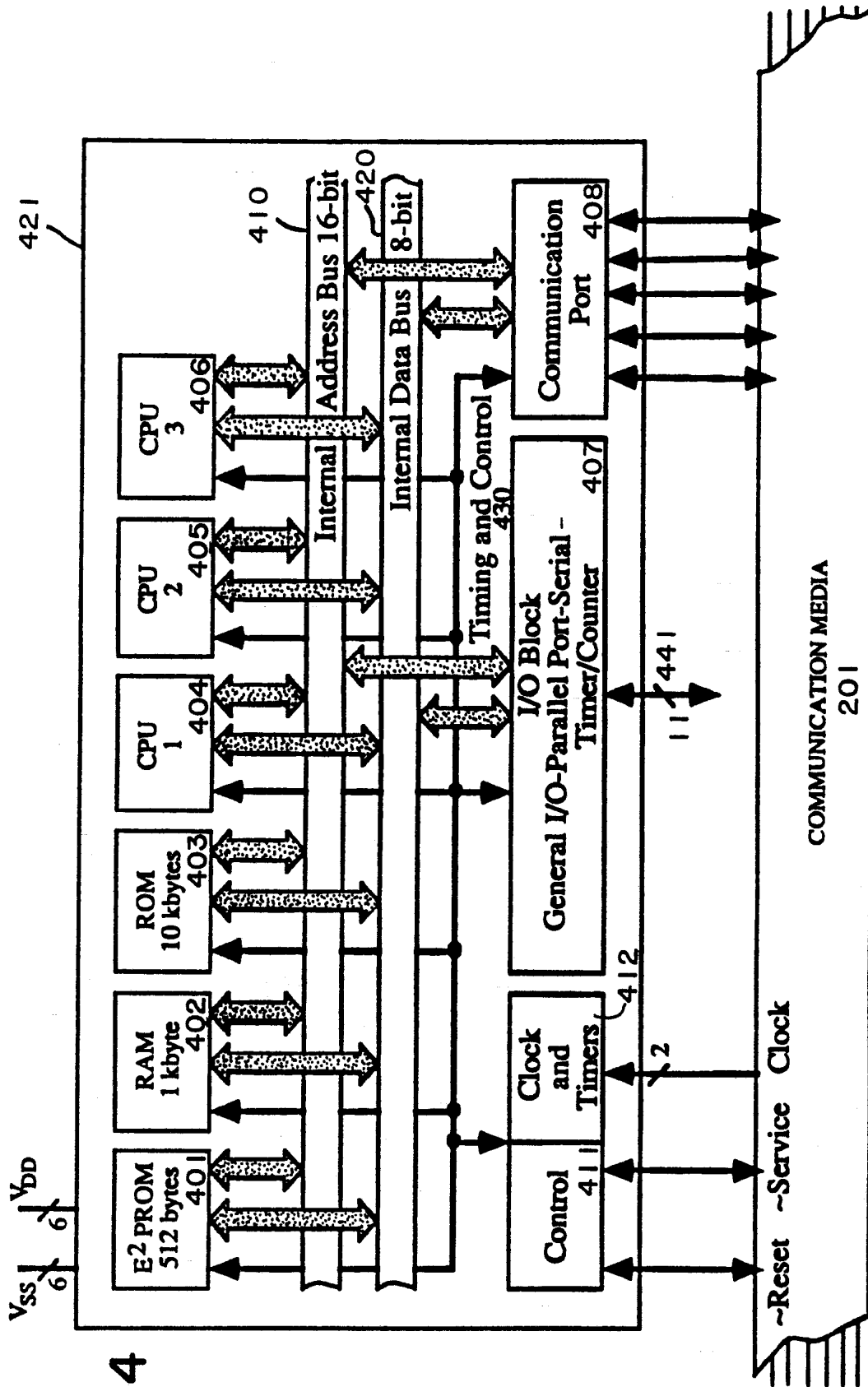


FIG. 4

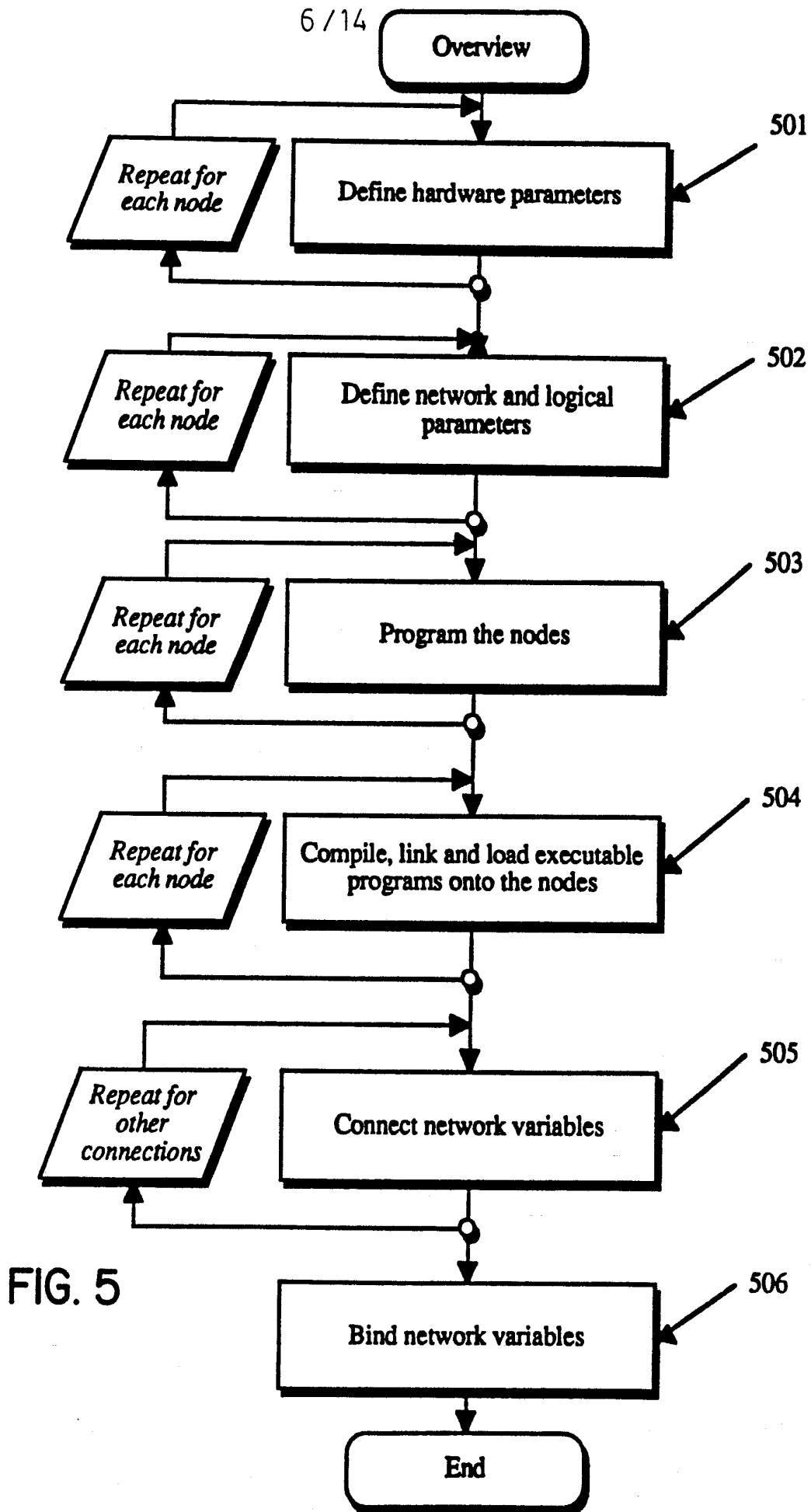


FIG. 5

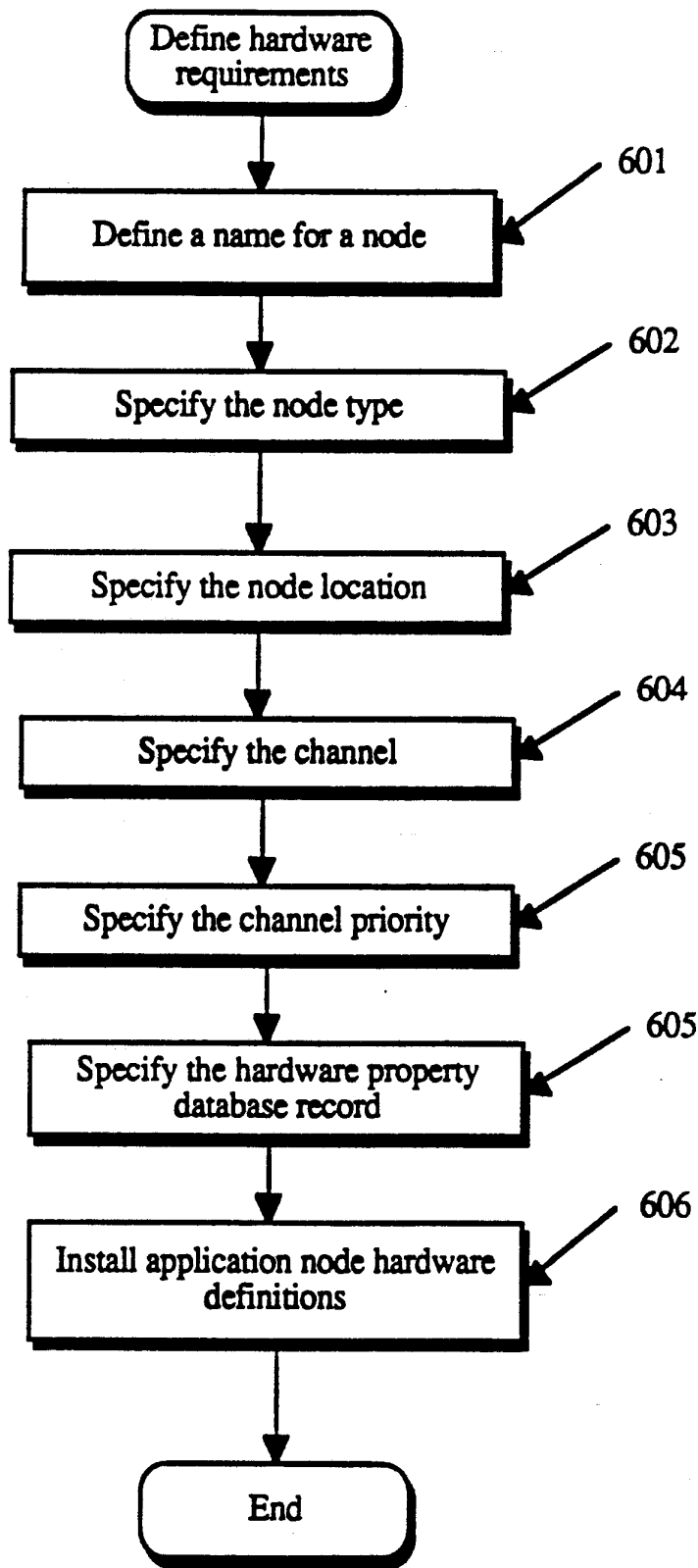


FIG. 6

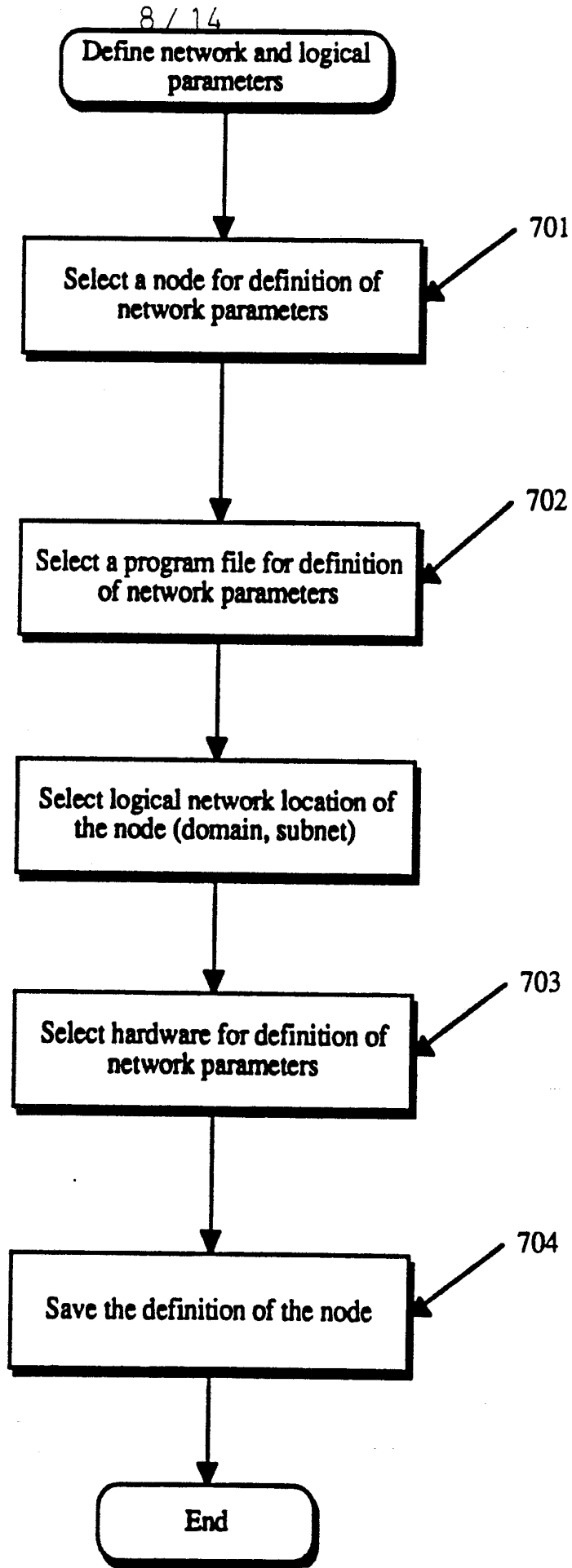


FIG. 7

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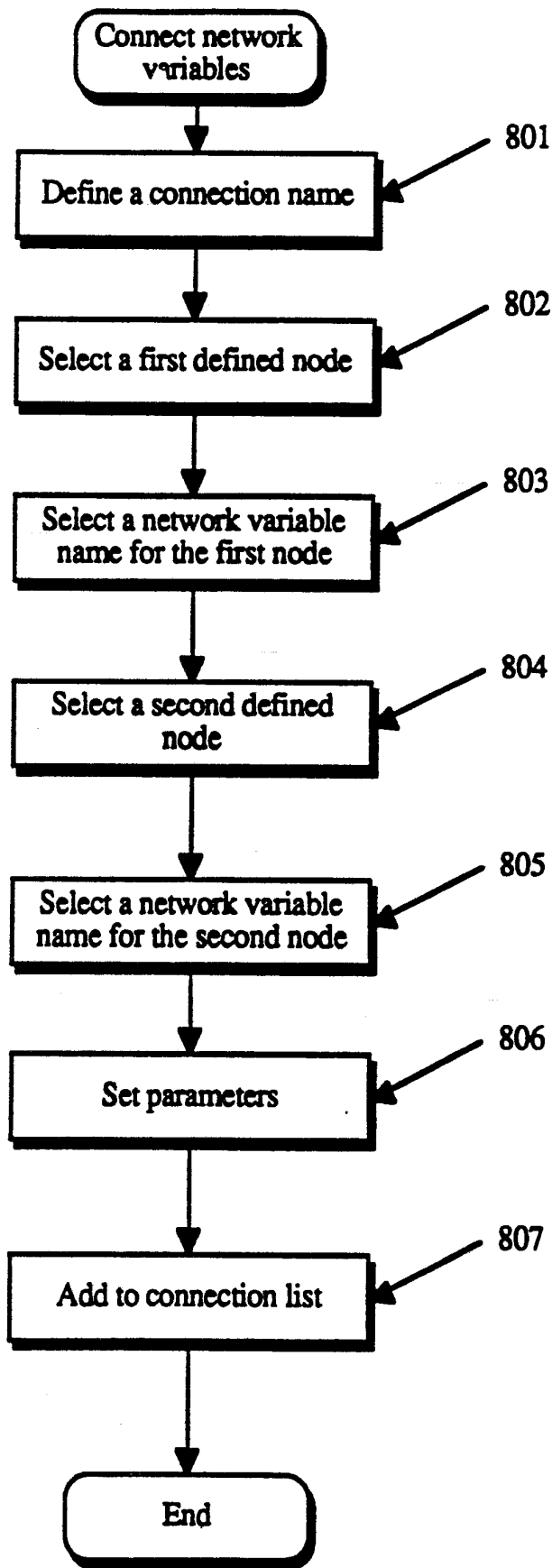


FIG. 8(a)

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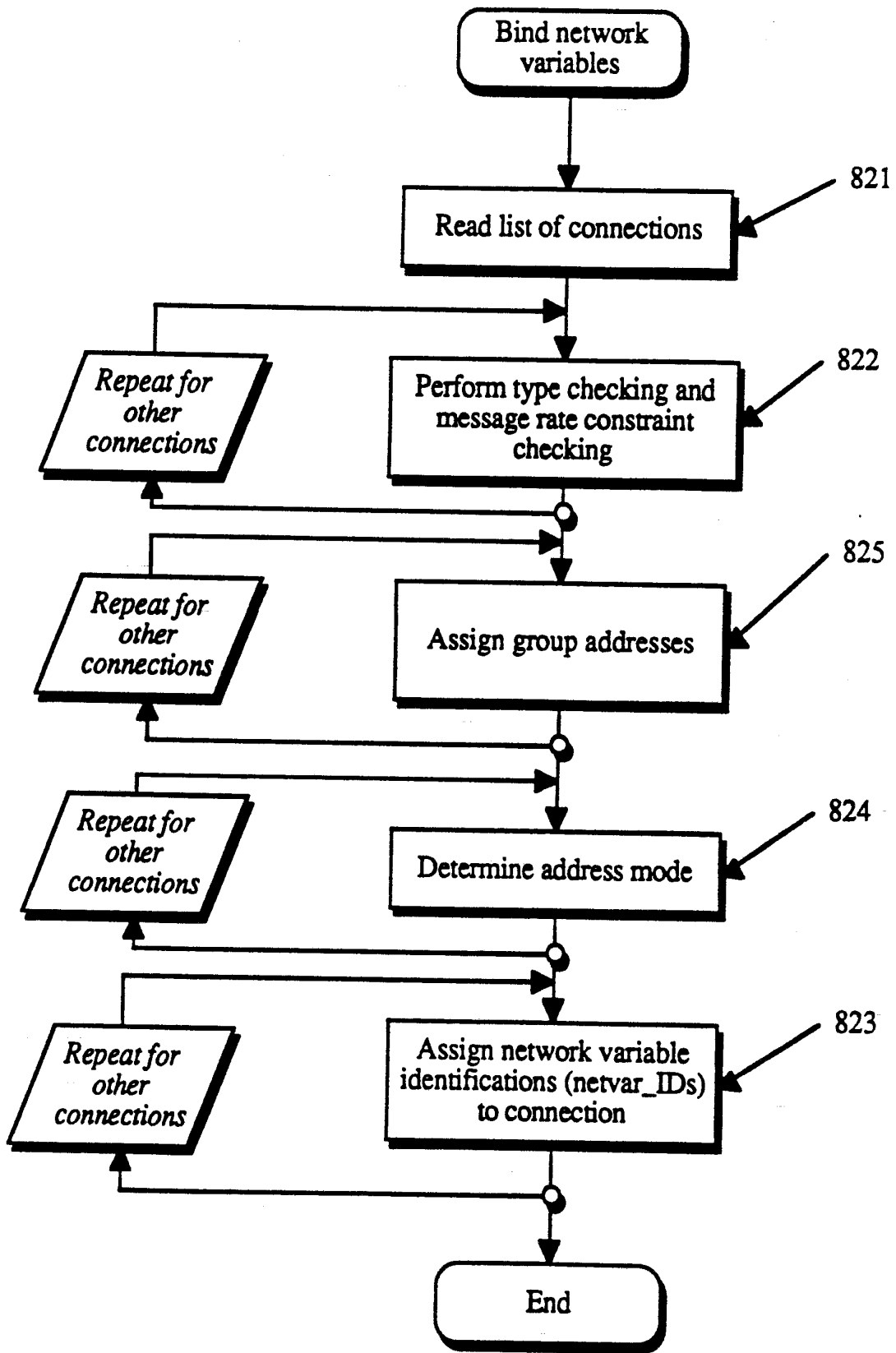


FIG. 8(b)

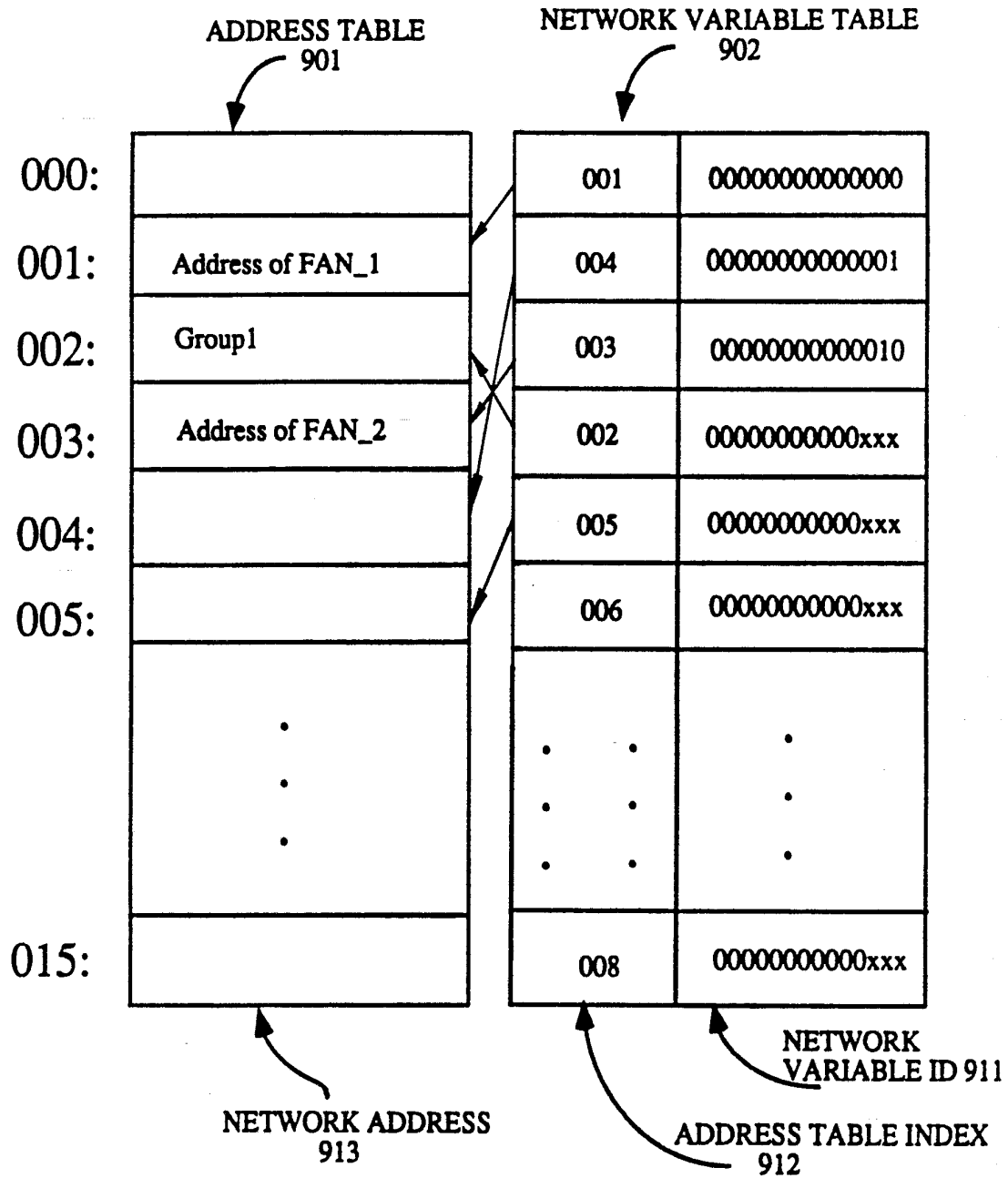


FIG. 9

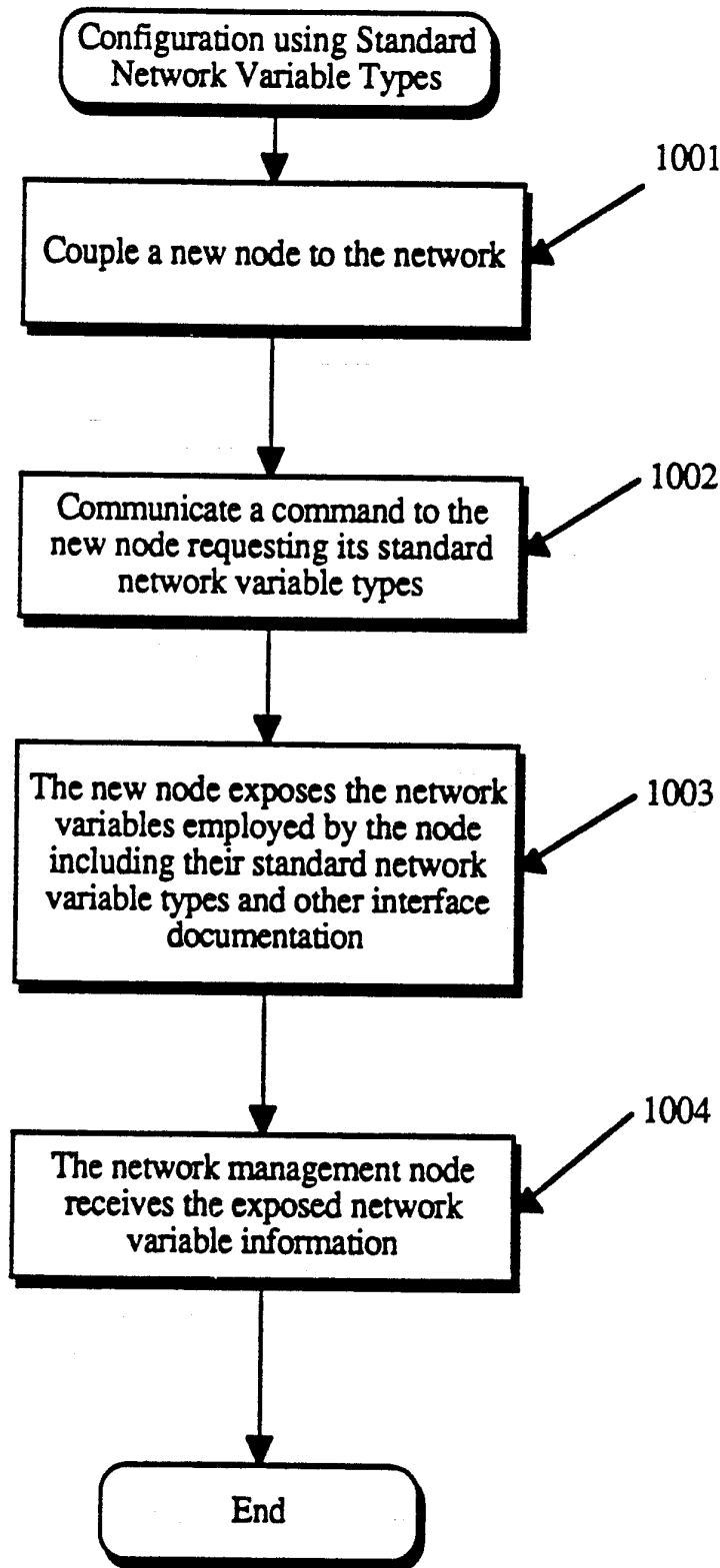


FIG. 10

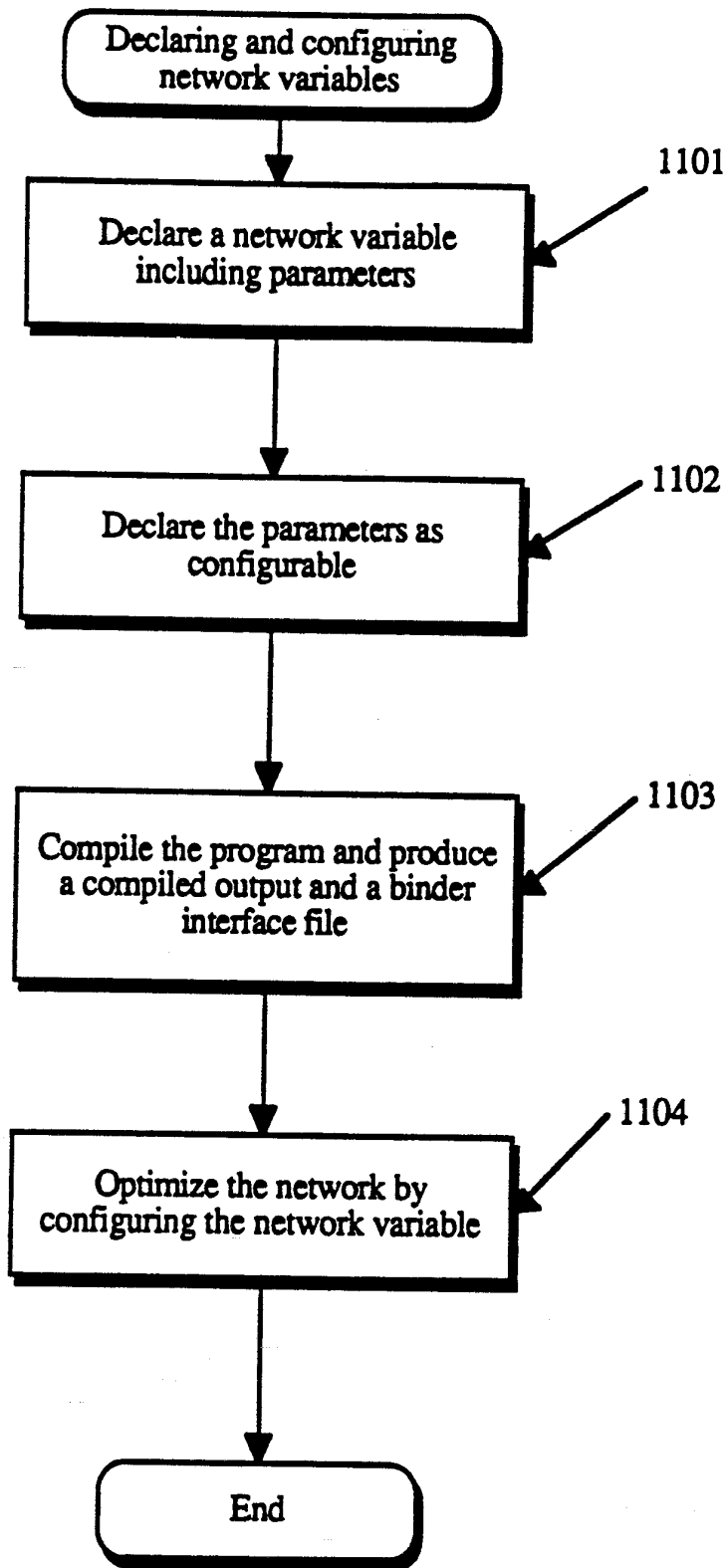


FIG. 11

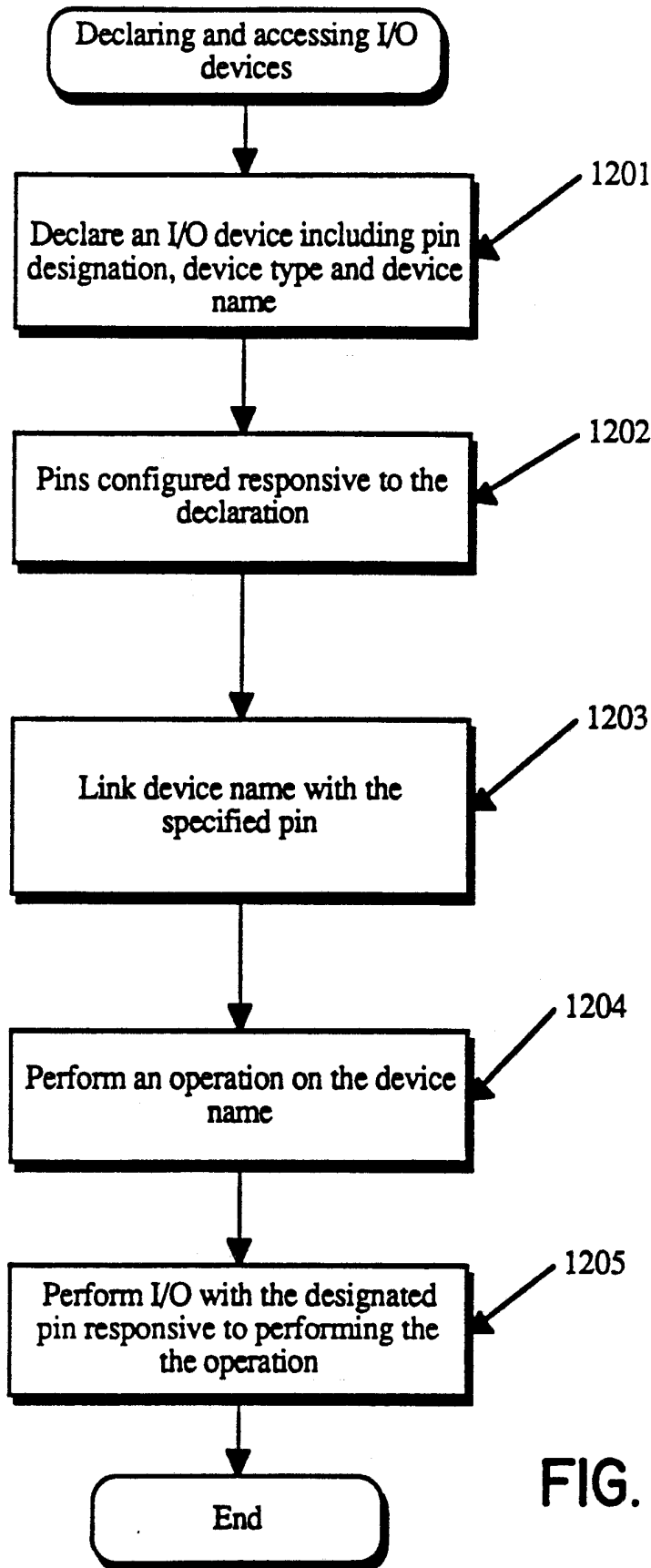


FIG. 12

INTERNATIONAL SEARCH REPORT

International Application No. PCT/US92/02147

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) ⁶		
According to International Patent Classification (IPC) or to both National Classification and IPC IPC (5): G06F 13/00 U.S.CL.: 395/200		
II. FIELDS SEARCHED		
Minimum Documentation Searched ⁷		
Classification System	Classification Symbols	
U.S.	395/200, 325, 800	
Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched ⁸		
III. DOCUMENTS CONSIDERED TO BE RELEVANT ⁹		
Category ¹⁰	Citation of Document, ¹¹ with indication, where appropriate, of the relevant passages ¹²	Relevant to Claim No. ¹³
X, T	US, A, 5,101,348 (ARROWOOD ET AL.) 31 March 1992 See col. 2, lines 8-48, col. 6, lines 15-68, col. 7, lines 1-31, the abstract, and the claims.	1-24
<u>Y</u> A	US, A, 4,654,654 (BUTLER ET AL.) 31 March 1987 See col. 2, lines 42-68, col. 5, lines 14-25, and claims 1-8.	1,11,17,20,23, 24 2-10,12-16,18, 19,21,22
<u>Y</u> A	US, A, 4,568,930 (LIVINGSTON ET AL.) 04 February 1986 See col. 7, lines 38-50.	1, 6-10, 17 2-5, 11-16, 18-24
A	US, A, 4,926,375 (MERCER ET AL.) 15 May 1990 See the entire document.	1-24
<p>¹⁰ Special categories of cited documents:</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.</p> <p>"&" document member of the same patent family</p>		
IV. CERTIFICATION		
Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report	
11 May 1992	04 JUN 1992	
International Searching Authority	Signature of Authorizing Officer	
ISA/US	Ayni Mohamed	