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INT CL **H04B, H05B**
Other: **Online: WPI, EPODOC, TXTE, Internet**

(54) Title of the Invention: **Power-line communication for non-domestic lighting**
Abstract Title: **Powerline communication mesh network for lighting**

(57) Lighting units 50a-d within a non-domestic building are each provided with a power-line communication (PLC) module. The power-line communication modulesestablish a mesh network within the power distribution circuit 10 of the non-domestic building, in which each lighting unit 50a-d acts as a node of the mesh network. The PLC mesh network additionally includes a head-end device to control routing across the network. The network facilitates "smart lighting" solutions. The lighting units may collect and transmit data relating to operating conditions of the lighting unit, or may incorporate sensors for determining occupancy. The lighting units may communicate with additional devices 42, 44 either wirelessly or using a wired connection. The lighting unit may receive commands from a computing device 42 or act as an access point for electronic shelf labels 44.

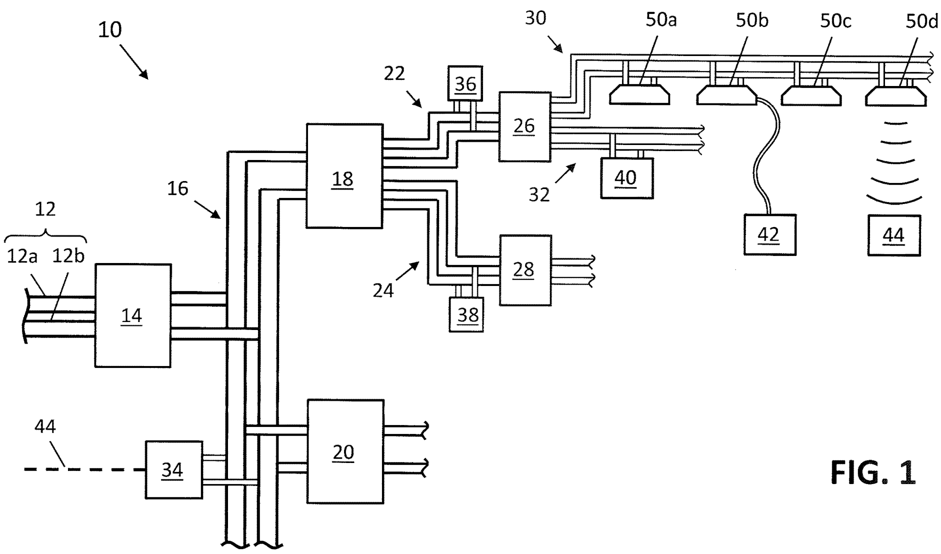

FIG. 1

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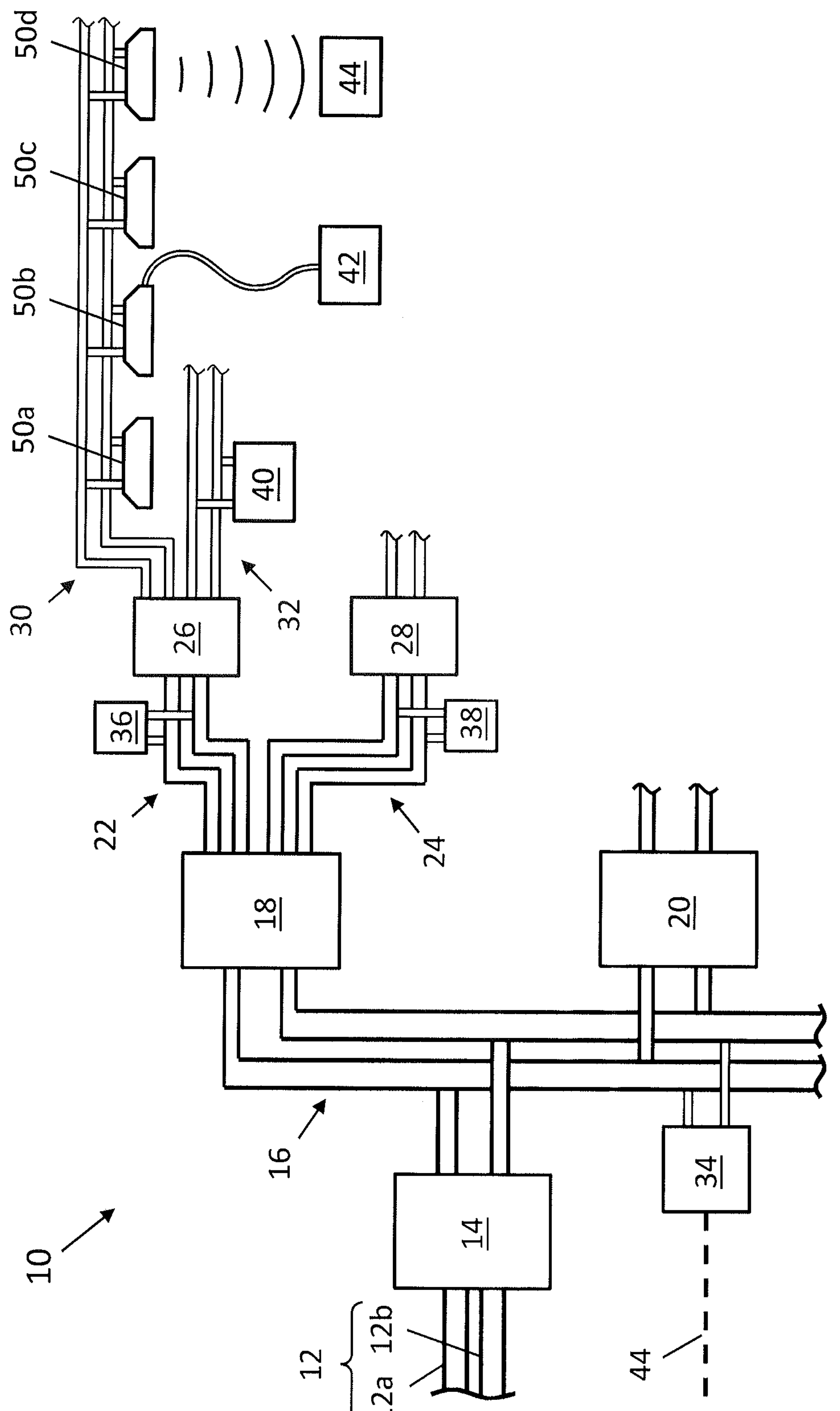

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FIG. 1

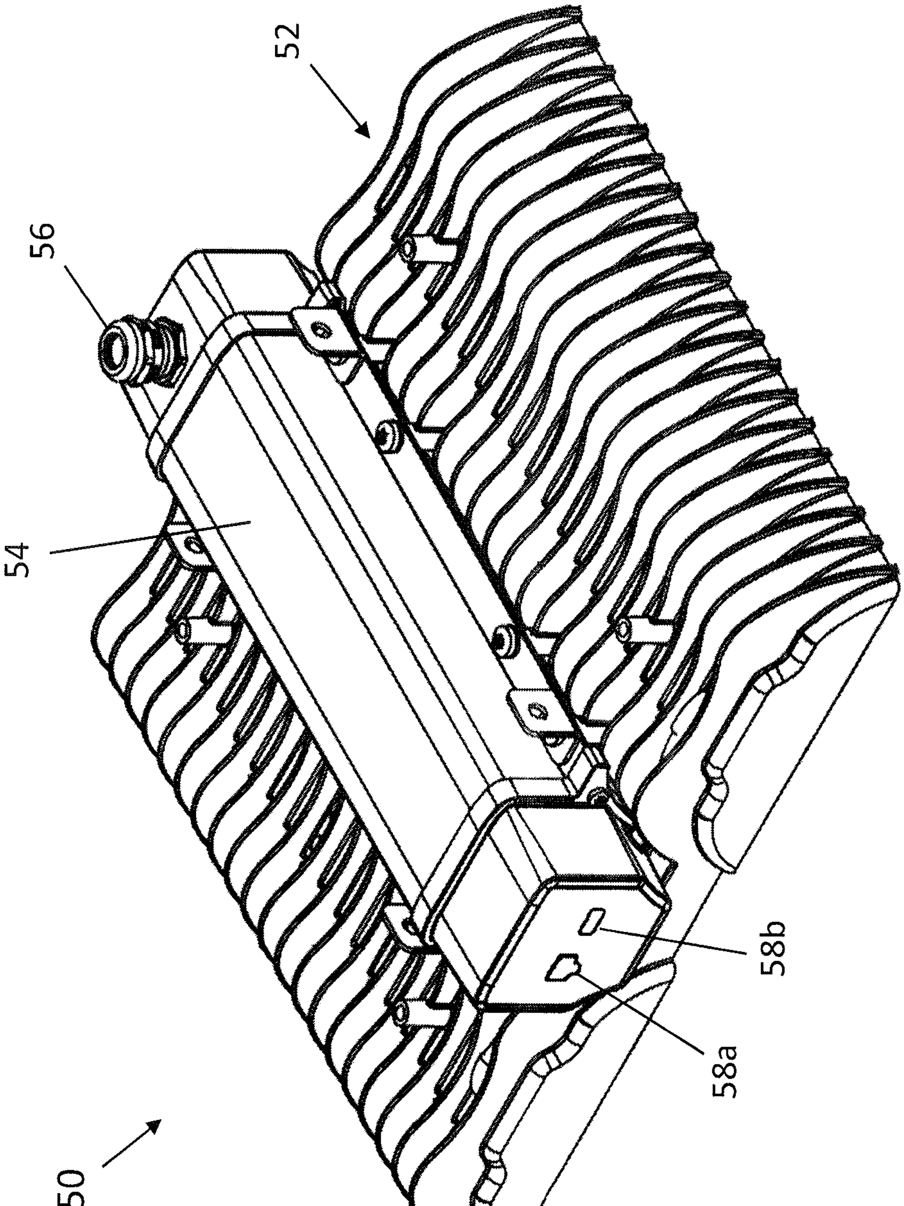

FIG. 2

01 12 16

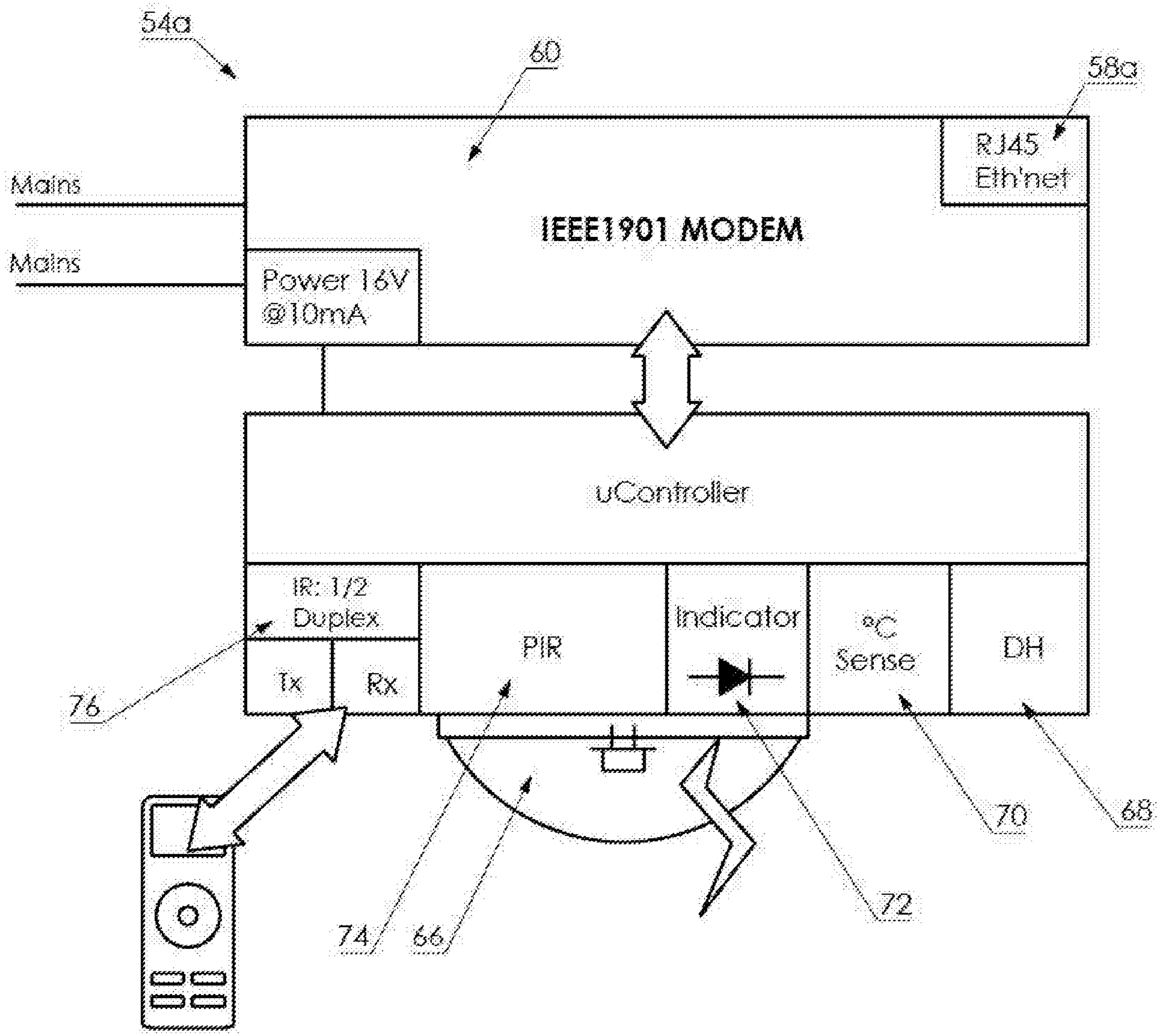
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FIG. 3

01 12 16

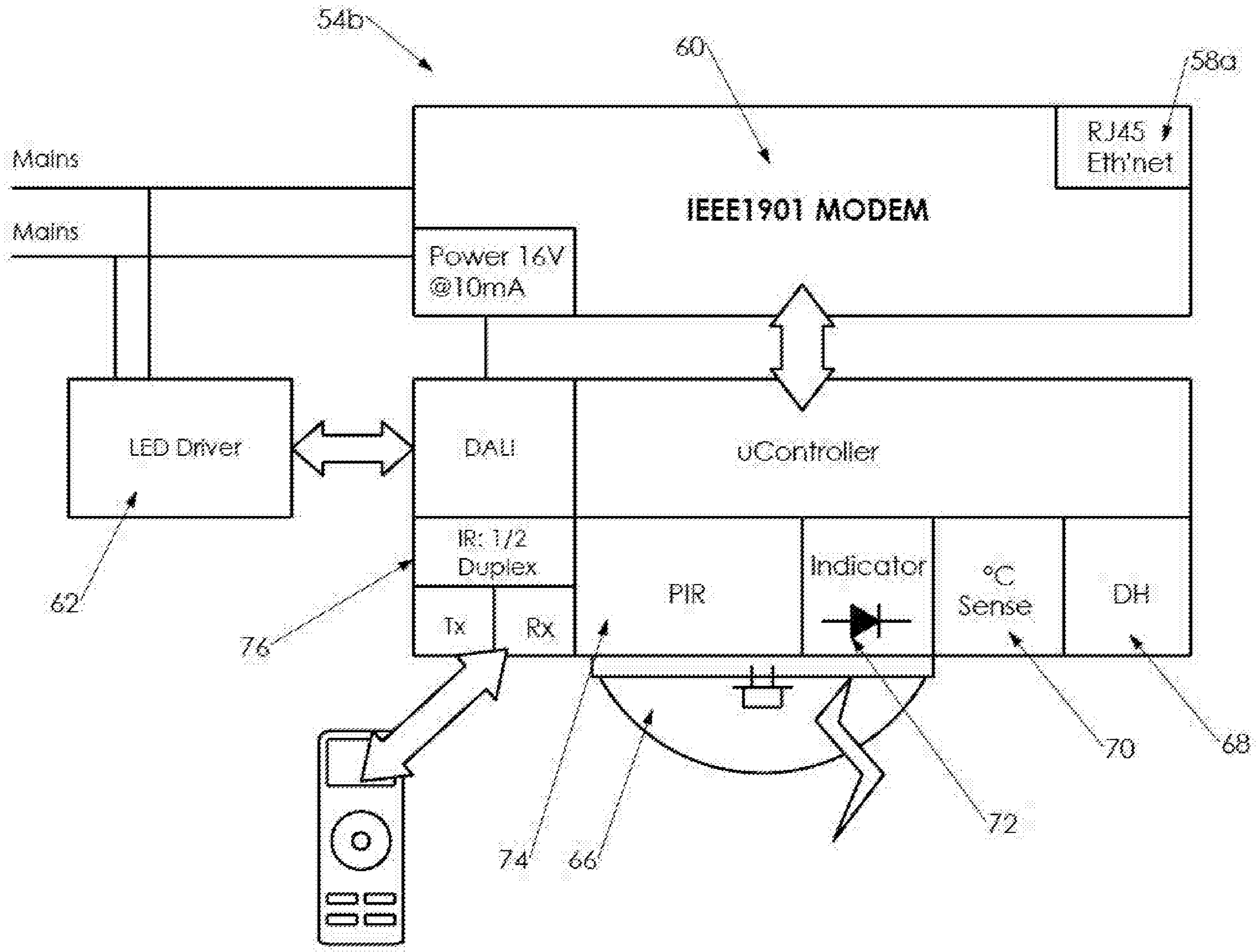
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FIG. 4

POWER-LINE COMMUNICATION FOR NON-DOMESTIC LIGHTING

The present invention relates to the use of power-line communication in non-domestic buildings.

In typical non-domestic buildings, such as stores, office spaces, factories and the like, it may be desirable to introduce new services. These may include services such as “smart lighting” (where each lighting unit can be controlled individually for optimal efficiency), as well as other services such as occupancy monitoring, public and/or private Wi-Fi networks, wirelessly controlled devices (such as electronic shelf labels), public announcement systems, and the like.

For each new service, it is common for dedicated wiring to be added to the building to connect the necessary wired terminals (such as wireless access points, speakers, cameras etc.) to a central control point. This adds significant expense and disruption, which in many cases means that new services are not added unless absolutely required.

Power-line communication uses the existing electric power distribution wiring to transmit data between devices connected to the power distribution wiring. Power-line communications systems operate by adding a modulated carrier signal to the wiring. However, since power distribution systems are typically designed for transmission of AC power at frequencies of 50 or 60 Hz, power line wiring often has only a limited ability to carry higher frequencies. Furthermore, the various electrical devices drawing power from the circuit generate high levels of noise. This combination of factors limits the effective range of power-line communication to around 50-100 meters along power-line cables within a building.

This range is adequate for domestic applications, but means that power-line communication has not seen any significant uptake in non-domestic application. For example, in larger, non-domestic buildings, such as those having a floor space of over 2000 m^2, the rapid signal degradation means that reliable communication across the building has not been possible.

The present invention seeks to provide a solution to the problems discussed above. Briefly, the present invention relates to the use of lighting units including power-line communication modules to establish a mesh network within a power distribution circuit of a non-domestic building. Each lighting unit acts as a node within the mesh network to allow communication across the entire building. Because lighting fixtures are located throughout the entire building, usually within transmission range of at least one other lighting unit, by providing a power-line communication modem in each unit, a reliable communication network can be established throughout the building without the cost and disruption of installing new wiring (only the lighting units need to be replaced).

The power-line communication mesh network allows the lighting units to communicate across the building. This allows for both monitoring and control of each individual lighting unit, i.e. smart lighting. Furthermore, by establishing a mesh network, other devices connected to the power distribution wiring that include a power-line communication module can also then communicate with any other device connected to the power distribution wiring via the mesh network established between the lighting units.

The present invention is applicable to non-domestic buildings, and particularly to non-residential, non-domestic buildings, such as commercial and/or industrial buildings. In the present context, a domestic building is a dwelling designed for a single family unit and may include, for example, a house, an individual flat or a maisonette.

Examples of non-domestic buildings include, for example, airports, shops, supermarkets, department stores, shopping malls, covered markets, offices, factories, warehouses, hospitals, prisons, cinemas, theatres, churches, galleries, exhibition spaces, leisure centres, hotels, public houses, car parks, stations, bus terminals, and the like. The present invention may also be applicable to, for example, non-domestic areas of residential buildings, for example common areas of a block of flats, a nursing home, a care home, or the like.

The present invention is most applicable to large buildings having a floor space of at least 2000 m^2 and typically a floor-to-floor or floor-to-ceiling height of between 2 and 15 meters, preferably between 3 and 15 meters.

Various preferred aspects of the present invention will now be described.

Viewed from one aspect, the present invention provides a non-domestic building including an electric power distribution circuit, a plurality of lighting units connected to the power distribution circuit, and a head-end device connected to the power distribution circuit, wherein each of the plurality of lighting units comprises a power-line communication module, and wherein the plurality of lighting units form a mesh network via power-line communication to allow the head-end device to communicate with a target device using the mesh network.

Thus, in this configuration, the power distribution circuit is used to establish a mesh network allowing power-line communication with the head-end device across the entire breadth of the network, typically across the entire building (although not necessarily the entire power distribution circuit). In large, non-domestic buildings, this is a larger range than is achievable through simple, non-repeated power-line communication.

The wide-area, power-line communication mesh network established in accordance with the present invention enables not only smart control of the lighting units by power-line communication, but also provides a wide-area network that can be used to facilitate other services within the building, and which can be established quickly without requiring additional wiring to be installed.

Typically the lighting units are connected to a lighting power distribution sub-circuit, which is a portion of the power distribution circuit that provides power only to the lighting units within the building. However, the lighting circuit is typically still in electrical communication with other power distribution sub-circuits (such as a motive power distribution sub-circuit) within the building and the range of the power-line communication network is therefore not limited to a particular sub-circuit.

Circuit breakers within the power distribution circuit may be used to separate different sub-circuits. Circuit breakers cause attenuation of the signal, but typically do not completely block it. For example, the head-end device may be connected such that there is one or more circuit breakers or fuses within the power distribution circuit between the head-end device and the plurality of plurality lighting units. In one embodiment, the head-end device is connected to a main power distribution bus of the power distribution circuit, which is separated from the lighting power distribution sub-circuit by at least one circuit breaker or fuse.

In one embodiment, the non-domestic building may further comprise one or more non-lighting device connected to the power distribution circuit and that includes a power-line communication module, the or each non-lighting device acting as a node in the mesh network. The non-lighting device may be a repeating device, i.e. serving no other function than to act as a node in the network.

The use of such a non-lighting unit is most applicable where there is a long distance between adjacent nodes of the network. Thus, the non-lighting unit may be separated from the head-end device and/or the lighting power distribution sub-circuit by at least one circuit breaker or fuse

Preferably a controller is configured to control each of the plurality of lighting units, preferably individually, via the power-line communication network. The controller may be provided within the head-end device.

In certain embodiments, one (or more) of the plurality of lighting units is adapted to enable communication with an external device that is not connected to the power distribution circuit and/or that does not include a power-line communication module. For example, the lighting unit may include an external port or lead for wired communication with the external device. The lighting unit may also or alternatively include a wireless communication module for wireless communication with the external device. The wireless communication module may be integral within a housing of the lighting unit or may be external to a housing of the lighting unit and connected to the lighting unit, for example, via a cable.

In this configuration, the lighting unit acts as an access point to enable the external device to communicate with the head-end device without the need for the external device to include a power-line communication module. Thus, an external device having a more common mode of communication, such as DALI, Ethernet, WiFi, Bluetooth, Infrared etc. may still communicate with the head-end device through the wireless communication network without special modification. In various embodiments, the mode of communication may include any communication media compatible with the KNX protocol, or other similar BMS (building management system) protocol.

Thus, in one embodiment, where the target device is not connected to the electric power distribution circuit and/or does not include a power-line communication module, the one or more of the lighting units includes or is connected to a wireless communication module for enabling the target device to communicate with the head-end device via a wireless network between the target device and the wireless communication module and via the power-line communication network between the power-line communication module and the head-end device.

The wireless transmitter may be, for example, a Radio communication module, an Infrared communication module, a Wi-Fi communication module, a Bluetooth communication module, a ZigBee communication module, an induction communication module (such as a near-field communication module), or the like.

The target device could be, for example, a mobile computing device, such as a mobile phone or tablet computer. Thus, a user of the device can access the network via, for example, Wi-Fi to connect to the Internet or an intranet.

The target device could alternatively be a remote-controlled device. Such devices can then be controlled remotely (either by wires or wirelessly) within the building without needing to install a separate infrastructure. In one example, the target device is a display device, such as an electronic shelf label or the like. Such devices are typically located throughout the entire building and would otherwise require significant service wiring to be installed.

Thus, in a preferred aspect, the present invention provides an electronic shelf label system comprising: a plurality of electronic shelf labels, an electric power distribution circuit, a plurality of lighting units connected to the power distribution circuit, one of the lighting units including a wireless communication module, and a head-end device connected to the power distribution circuit, wherein each of the plurality of lighting units comprises a power-line communication module, wherein the plurality of lighting units form a mesh network via power-line communication to allow the head-end device to communicate with the plurality of electronic shelf labels using the mesh network and the wireless communication module.

In another embodiment, the target device may be a non-connected lighting unit that is not connected to the electric power distribution circuit (or is connected to a different electric power distribution circuit) or that does not include a power-line communication module. The one of the plurality of lighting units may then be adapted to enable communication with the non-connected lighting unit without using power-line communication. For example, the one of the lighting units could use DALI/ZigBee locally to communicate with the non-connected lighting unit. In other embodiments, the one of the lighting units may use the KNX protocol, or other similar BMS (building management system) protocol, to communicate with the non-connected lighting unit via any suitable communication media except power-line communication.

Where the system includes a controller, the controller is preferably also able to control the non-connected lighting unit via the power-line communication network.

Such a configuration may be advantageous to minimise the number of devices communicating on the power-line communication network, as the network bandwidth may be limited where a large number of lighting units in close proximity act as nodes. This configuration may also be advantageous where multiple lighting power distribution circuits are used for the lighting units (or where lighting units are connected to non-lighting power distribution circuits), but only one circuit is used for power-line communication.

Preferably one or more, or each, of the plurality of lighting units (or the non-connected lighting unit) comprises a controller capable of monitoring one or more properties of the lighting unit and the controller is configured to transmit monitored data to the head-end device via the power-line communication mesh network. The monitored data is preferably transmitted periodically to the head-end device.

The one or more properties may include a property affecting the lifetime of the lighting unit. For example, the one or more or more properties may include at least one of: an operational temperature of the lighting unit; a power consumption of the lighting unit; an ambient temperature of surrounding environment; and humidity/moisture of the surrounding environment.

By measuring and monitoring these parameters, it is possible to more accurately estimate the remaining lifetime of the lighting units. This has not been possible in existing “smart lighting” solutions using DALI or ZigBee because these infrastructures cannot handle the high query rate required.

The one or more properties may also or alternatively include data suitable for determining occupancy within the surrounding environment. Whilst occupancy can be inferred from certain data (such as assuming occupancy when the lighting unit is active), the data is preferably suitable for positively determining occupancy, such as data from a video camera, a motion detector, a passive infrared detector, or the like. The data suitable for determining occupancy could also include an indication of occupancy, i.e. a binary value of occupied or unoccupied, for example where the data processing is performed locally to the lighting unit. This could be an indication of occupancy in the vicinity of the specific lighting unit, or for regions of the building, for example rooms or areas within a floor space.

In various embodiments, the head-end device may include a connection for communication externally of the building, for example an internet connection. Such a connection may enable remote monitoring and/or control of the lighting units and/or of the network.

The mesh network may also facilitate communication between the head-end device and a non-lighting device connected to the power distribution circuit, where the non-lighting device includes a power-line communication module. Such a device may include, for example, a computing device, a remotely-controlled device, a controller for the lighting units, which could be a simple light switch or a more complex computing device, or any other device connected to the power distribution circuit. Thus, the building may further comprise a non-lighting device connected to the power distribution circuit, wherein the non-lighting device includes a power-line communication module and is adapted to communicate with the head-end device via the power-line communication mesh network.

The above described system may be implemented on a single circuit. For example, it could be implemented on a single phase circuit where the building is supplied with multi-phase electricity, or it could be implemented on the live or neutral lines of a building receiving single-phase electricity. In order to increase the available bandwidth within the building, the system may optimally form a power-line communication network on a second circuit.

Thus, in one embodiment, the electrical distribution circuit comprises a first circuit and a second circuit, the plurality of lighting units being adapted to form a first mesh network via power-line communication on the first circuit and a second mesh network via power-line communication on the second circuit. As discussed above, the first and second circuits may be live and neutral circuits or first and second phase circuits.

In another embodiment, the electrical distribution circuit comprises a first sub-circuit and a second sub-circuit, wherein the plurality of lighting units are adapted to form a first mesh network via power-line communication on the first sub-circuit and a second mesh network via power-line communication on the second sub-circuit. The sub-circuits may, for example, be different lighting circuits, such as for different floors of the building, or different types of sub-circuit, such as a lighting circuit and a ring circuit, which could be within a single floor of the building.

Viewed from another aspect, the present invention can also be seen to provide a method of communication between a head-end device and a target device within a non-domestic building, the building including an electric power distribution circuit and a plurality of lighting units connected to the power distribution circuit, the method comprising: establishing a mesh network via power-line communication, wherein the lighting units act as mesh nodes of the network; and transmitting data between a head-end device and a target device via the power-line communication network.

Similar to the configuration discussed above, the method may facilitate communication between the head-end device and a target device that is not connected to the power distribution circuit or that does not include a power-line communication module.

Thus, where the target device is not connected to the electric power distribution circuit and/or does not include a power-line communication module, the step of transmitting may include transmitting data between the head-end device and a lighting unit via the power-line communication network, and transmitting data between the lighting unit and the target device via non-power-line communication.

As above, the non-power-line communication may include wireless communication, for example, Infrared communication, Wi-Fi communication, Bluetooth communication, ZigBee communication, or the like. The target device may include, for example a mobile, personal computing device, such as a mobile phone or tablet computer.

The target device may include a remote-controlled device. In one example, the target device is a display device, such as an electronic shelf label or the like. In one embodiment, the present invention can be seen to provide a method of controlling a remotely-controlled device, comprising: sending an instruction to the remotely-controlled device by the method described above, wherein the display device does not include a power-line communication module or is not connected to the power distribution circuit.

In another embodiment, the target device may be a non-connected lighting unit that is not connected to the electric power distribution circuit (or is connected to a different electric power distribution circuit) or does not include a power-line communication module. The one of the plurality of lighting units may then be adapted to enable communication with the non-connected lighting unit without using power-line communication. For example, the one of the lighting units could use DALI/ZigBee locally to communicate with the non-connected lighting unit.

In a preferred aspect, the method of communication is a method of communication between a sending device and the target device via the head-end device, the method further comprising transmitting the data via the power-line communication network from the sending device to the head-end device for transmission to the target device.

Viewed from another aspect, the present invention provides a method of controlling a target lighting unit installed within a non-domestic building, the method comprising: transmitting a lighting command from the head-end device to the target lighting unit using the method above. The lighting unit may be one of the plurality of lighting units or it may be a non-connected lighting unit.

Viewed from another aspect, the present invention provides a method of monitoring a target lighting unit installed within a non-domestic building; the method of monitoring may be used in combination with the method of controlling the target lighting unit discussed above. The method of monitoring comprises: monitoring one or more properties of the lighting unit or its surrounding environment to determine monitored data; and transmitting the monitored data to a head-end device using the method above.

As above, the lighting unit may be one of the plurality of lighting units or it may be a non-connected lighting unit. Preferably the method comprises periodically transmitting the monitored data to the head-end device.

The one or more properties may include a property affecting the lifetime of the lighting unit. For example, the one or more or more properties may include at least one of: an operational temperature of the lighting unit; a power consumption of the lighting unit; an ambient temperature of surrounding environment; and humidity/moisture of the surrounding environment.

By measuring and monitoring these parameters, it is possible to more accurately estimate the remaining lifetime of the lighting units. The method may therefore further comprise calculating or adjusting an estimate of the remaining lifetime of the lighting unit based on the monitored data.

The one or more properties may also or alternatively include data suitable for determining occupancy within the surrounding environment. Whilst occupancy can be inferred from certain data (such as assuming occupancy when the lighting unit is active), the data is preferably suitable for positively determining occupancy, such as data from a video camera, motion detector, passive infrared detector, or the like. Such data should also be considered to include a determination of occupancy, i.e. a binary value of occupied or unoccupied, for example where the data processing is performed locally to the lighting unit.

In one embodiment, the occupancy data may be used for security purposes. For example, the method may comprise monitoring occupancy in the vicinity of each of the lighting units and generating an alert when occupancy is detected at a predetermined time and location. For example, an alert may be raised when occupancy is detected within a secure location at a time when it should not be occupied.

By including monitoring capabilities in each lighting unit, occupancy can be precisely monitored, for example an alert could be raised when occupancy is detected at night within one part of the building, or even one area of a room, which should be unoccupied, whilst not raising an alert due to anticipated occupancy in other areas, for example security guards or the like.

Viewed from another aspect, the present invention can also be seen to provide a lighting unit for use in one or more of the systems and methods described above.

For example, the present invention may provide a lighting unit for connection to an electric power distribution circuit, the lighting unit comprising: a luminaire portion for emitting light; and a power-line communication module for communicating with a power-line communication network, the power-line communication module being configured to establish a mesh network via power-line communication with at least one additional lighting unit connected to the electric power distribution circuit.

The lighting unit may be adapted for communicating with another device (i.e. one that is not part of the lighting unit) that does not include a power-line communication module and/or when it is not connected to the electric power distribution circuit.

In one embodiment, the lighting unit may further comprise a wireless communication module for communicating with an external target device that does not include a power-line communication module or is not connected to the electric power distribution circuit, wherein the lighting unit is configured to enable the external target device to communicate with a head-end device connected to the power-line communication network.

In another embodiment, the lighting unit comprises a port or cable for wired communication with an external target device that does not include a power-line communication module, wherein the lighting unit is configured to enable the external target device to communicate with a head-end device connected to the power-line communication network.

The lighting unit may also or alternatively include a monitoring portion for monitoring one or more properties of the lighting unit or its surrounding environment, wherein the monitoring portion is configured to transmit monitored data to a head-end device via the power-line communication network. The monitoring portion is preferably configured to periodically transmit the monitored data to the head-end device.

The one or more properties monitored by the monitoring portion may include one or more properties affecting the lifetime of the lighting unit. For example, the one or more or more properties may include at least one of: an operational temperature of the lighting unit; a power consumption of the lighting unit; and an ambient temperature of surrounding environment.

The one or more properties may also or alternatively include data suitable for determining occupancy within the surrounding environment. Whilst occupancy can be inferred from certain data (such as assuming occupancy when the lighting unit is active), the data is preferably suitable for positively determining occupancy, such as data from a video camera, motion detector, passive infrared detector, or the like. Such data should also be considered to include a determination of occupancy, i.e. a binary value of occupied or unoccupied, for example where the data processing is performed locally to the lighting unit.

As discussed above, the lighting unit is preferably a non-domestic lighting unit. Such a lighting unit may have, for example, a lumen output of at least *....*.

Certain of the above features may be applicable in systems that do not use meshing. These systems may be applicable in smaller-scale buildings that do not require meshing, but still benefit from the synergistic effect of employing lighting units to provide access points to a power-line communication network.

Thus, in another aspect, there may be provided a lighting unit comprising: a luminaire portion for emitting light, and a power-line communication module for communicating with a power-line communication network, wherein the lighting unit is configured to enable an external target device, which does not include a power-line communication module or is not connected to the electric power distribution circuit, to communicate with a head-end device connected to the power-line communication network.

As above, the lighting unit may comprise a wireless communication module for communicating with the external target device, wherein the lighting unit is configured to enable the external target device to communicate with a head-end device connected to the power-line communication network.

The lighting unit may instead comprise a port or cable for communicating with the external target device.

In yet another aspect, there may be provided a lighting unit comprising: a luminaire portion for emitting light, a monitoring portion for monitoring one or more properties of the lighting unit or its surrounding environment, and a power-line communication modem for communicating with a power-line communication network; the monitoring portion being configured to transmit monitored data to a head-end device via the power-line communication network.

As discussed previously, by measuring and monitoring certain parameters, it is possible to more accurately estimate the remaining lifetime of the lighting units. This has not been possible in existing "smart lighting" solutions using DALI or ZigBee because these infrastructures cannot handle the high query rate required.

These alternative aspects may optionally include any or all of the preferred features discussed above in respect of the meshing lighting units.

Viewed from another aspect, the present invention provides a method of retrofitting a non-domestic building including an electric power distribution circuit and a plurality of existing lighting units connected to the distribution circuit, the method comprising: removing the existing lighting units; installing replacement lighting units to replace the existing lighting units, the replacement lighting units each including a power-line communication module; and connecting a head-end device to the distribution circuit, wherein the plurality of lighting units form a mesh network via power-line communication to allow the head-end device to communicate with a target device.

In accordance with this method, a power-line communication network can be quickly and easily established in an existing building without requiring any new wiring to be installed. In particular, light fittings are often modular and so can typically be replaced without requiring significant disturbance or access to the ceiling space, which would otherwise be required for installing new wiring. The new network also easily traverses walls and other structures that might otherwise impede new wiring.

The new network further allows additional services to be installed in the building, again without need for any additional wiring.

Certain preferred embodiments of the present invention will now be described in greater detail, by way of example only, with reference to the accompanying figures, in which:

Figure 1 is a schematic drawing illustrating part of a power distribution system of a non-domestic building;

Figure 2 is a perspective drawing of non-domestic lighting unit including a power-line communication modem;

Figure 3 is a schematic drawing illustrating a first configuration of the lighting unit; and

Figure 4 is a schematic drawing illustrating a second configuration of the lighting unit.

Figure 1 is a schematic drawing illustrating part of an electrical power distribution circuit 10 within a non-domestic building.

Electricity enters the building at standard voltage (in Europe: 230V for single-phase electricity and 400V for three-phase electricity) via a main power line 12. In many non-domestic buildings, the main power line 12 carries three-phase electricity. However, for convenience, the present embodiment is illustrated using single-phase electricity having a live wire 12a and a neutral wire 12b. In a three-phase electric system, the live wire 12s and the neutral wire 12b would instead correspond to two wires of different phases.

The main power line 12 is received within the building by a main switch 14. In non-domestic buildings, the main switch 14 can often be rated for currents of over 1000A, and for industrial buildings can be much higher.

From the main switch 14, the electricity is supplied to a main power distribution bus bar 16. Connected to the power distribution bus bar 16 are one or more distribution circuit breakers 18, 20. These circuit breakers 18, 20 each isolate one or more power distribution sub-circuits within the power distribution circuit 10. Typically the distribution circuit breakers 18, 20 will isolate sub-circuits having significantly different current draws. For example, one circuit breaker unit 18 may control the supply of electricity to offices and another circuit breaker 20 may control supply of electricity to a factory floor.

In the illustrated embodiment, distribution circuit breaker 18 supplies power to two sub-circuits 22, 24, which are each isolated by a respective distribution circuit breaker 26, 28. These two sub-circuits 22, 24 may, for example, be located on separate floors of the building such that the electric supply to each floor can be independently isolated by the respective breaker 18, which may be located in a central location.

In this drawing, distribution circuit breaker 26 is shown as supplying electricity to two further sub-circuits 30, 32: a lighting electrical distribution sub-circuit 30 and a ring electrical distribution sub-circuit 32. These sub-circuits are final sub-circuits and have electrical supply points that can be used to draw current from the distribution circuit 10.

As those familiar in the art will appreciate, subsequent circuit breakers and sub-circuit are rated for decreasing current. Furthermore, it will be appreciated that a greater or fewer number of tiers of circuit breakers will be required within different buildings depending upon their use. However, even small domestic buildings will typically be isolated by a circuit breaker into a number of final sub-circuits within the power distribution circuit, for example to isolate a ring circuit and a lighting circuit.

The power distribution circuit 10 itself is thus essentially conventional. A power distribution circuit 10 is normally installed at the time of construction of the building.

Attached to the power distribution circuit 10 are a number of peripheral devices that draw electricity from the power distribution circuit 10.

The peripheral devices illustrated in Figure 1 are a head-end device 34, two repeaters 36, 38, a plurality of lighting units 50a-d, and computing device 42. These devices each include a power-line communication module, as will be discussed in greater detail below, such that they can communicate with one another via power-line communication.

In the illustrated embodiment, the head-end device 34 is mounted to the bus bar 16. The head-end device 34 further includes an external connection 44, for example to the internet.

The two repeaters 36, 38 are connected, respectively, to the sub-circuits 22, 24 of distribution circuit breaker 18. Thus, in this embodiment, a repeater 36, 38 is located on each floor. It will be appreciated that, in a large, non-domestic building, the distance along the wiring of the power distribution circuit 10 between the head-end device 34 and lighting units 50a-d can be significant, particularly where the lighting units are located across multiple floors. However, in smaller buildings, it may be that the use of repeaters 36, 38 is not required.

The lighting units 50a-d shown in the illustrated embodiment are connected to the lighting electrical distribution sub-circuit 30. Two of the illustrated lighting units 50b, 50d are shown in communication with further additional devices 42, 44. Lighting unit 50b is adapted for wired communication with device 42 and lighting unit 50d is adapted for wireless communication with device 44.

The computing device 44 is another device that is connected to a separate electrical distribution sub-circuit from the lighting electrical distribution sub-circuit 30. In this embodiment, it is connected to the ring electrical distribution sub-circuit 32.

Figure 2 illustrates a perspective view of a lighting unit 100 for a non-domestic building. The lighting unit 50 may be used as one of the lighting units 50a-d shown in Figure 1.

The lighting unit 50 includes a luminaire portion 52 and a control portion 54.

The luminaire portion 52 is adapted to operate in the manner of a conventional luminaire, i.e. to emit light at a desired intensity in accordance with instructions from the control portion 54.

The control portion 54 includes the driver for the lighting unit 10. The control portion 54 also comprises an electrical connector 56 for connecting the lighting unit 50 to the power distribution circuit 10. The control portion 54 also comprises connectors 58 for communication with external devices, for example an Ethernet port 58a or a USB port 58b.

Figures 3 and 4 show exemplary configurations for the control protions 54a, 54b of a lighting unit 50. Figure 3 shows a sensor-only control portion 54a, and Figure 4 shows a lighting-and-sensor-control portion 54b.

Both units 54a, 54b contain at least one sensor 66-70 that communicates with a power-line communication module 60. In these embodiments each sensor has its own microcontroller which communicates its status with the module 60 (and therefore the rest of the system) via serial or similar interface.

Each unit 54a, 54b has a number of sensors 66-70 that provide data about the immediate environment of the unit 54a, 54b, such as occupancy, temperature, light level etc. Each unit 54a, 54b may contain some of at least the following sensors:

1) a Passive infra-red detector 64 and lens 66 that monitors the movement of people and machinery below the sensor;
2) a daylight harvesting (DH) sensor 68 that measures the level of visible light that is reflected from objects in the field of view of the sensor 68; and
3) an ambient temperature sensor 70.

The unit 54a, 54b may further comprise an indicator LED 72 that optionally shows status of the sensors 66-70 or unit 50a, 50b during commissioning, testing or operation. The unit 54a, 54b may also comprise a local communication channel 76 such as near IR that allows for communication with commissioning and test engineering or system operators.

In the Figure 4 embodiment, the unit 54b further comprises a communication interface such as DALI for communicating with the power supply for a luminaire portion 52 of the lighting unit 50 in order to control the power output and observe its behaviour and health such as temperature, power consumption etc. Luminaire driver 64 is connected to the uController via a Digital Addressable Lighting Interface (DALI) connection in this case.

Each module contains an auxiliary Ethernet interface 58a to which third parties can securely connect equipment for on going connection to the Internet or other networked equipment.

To enable or commission the system, software is provided that allows individual modules (luminaires or sensors) to join the system. Modules are joined by pushing them onto network (once previously opened for a fixed time) using a special function in the remote control. Once commissioned the module can be allocated a unique IP address that is permanently associated with that module and location. In this way access to the network is restricted to approved equipment and as each module (or node) is commission its location can be electronically associated with a particular fixed location in the building. Once commissioning is completed the network can be graphically represented as a “physical schematic” where the status of each of the nodes with respect to a particular sensor input (say light level) can be shown graphically at once by a series of colours or a heat map.

Addressing of each node can be performed by conventional mac addressing and IPv4 or IPv6 network addressing schemes.

The same power-line communication network provides all the modern features that are associated with management and control of modern networking equipment such as automatic or manual remote updating of firmware and other maintenance activities.

The power-line communication modules 60 of each of the lighting units 50 communicate with each other, with the power-line communication repeater 36, 38, with the computing device 42 and with the head-end device 34 in order to establish a network within the power distribution circuit. The network preferably complies with the IEEE 1901 standard, which can achieve data transfer speeds of up to 500 Mbit/s.

Each of the devices 34, 36, 38, 42, 50 forms a node within the network. As each device 34, 36, 38, 42, 50 may be able to communicate with more than one other device 34, 36, 38, 42, 50 connected to the circuit 10, it is possible to establish a mesh network between the devices 34, 36, 38, 42, 50.

The mesh network is dynamic and the nodes periodically determine the signal quality between neighbouring nodes (i.e. those nodes that are within communication distance). This information is relayed back to the head-end device 34. The head-end device 34 acts as a router for data within the mesh network and all data packages are either set to or from the head-end device 34 via a route determined by the head-end device 34.

For example, if a user of computing device 42 wishes to control lighting unit 50a, an instruction is sent to the head-end device 34 via the power-line communication network and then the head-end device 34 sends the instructions via the power-line communication network to the lighting unit 50a.

The repeaters 36, 38 simply act as additional nodes of the mesh network that are not necessarily used, but provide additional paths for data to be routed. For example, if there is little noise on the line, then the head-end device 34 may be able to communicate directly with computing device 42 and/or lighting unit 50a without needing to relay the data through the repeater 36. However, in this embodiment, such a signal must pass through two distribution circuit breaker 18, 26, which each causes attenuation of the signal and so the repeater may be necessary where there is significant attenuation from other sources, such as high noise or long travel distances.

The power-line communication preferably complies with the KNX network communications protocol for intelligent buildings (EN 50090, ISO/IEC 14543-3). However, other building system management system (BSM) protocols may be used where appropriate.

The primary function of the power-line communication network is to provide control of the lighting units 50. For example, an electronic switch (not shown) may be connected to the lighting electrical distribution sub-circuit 30. When pressed, an instruction is sent via the power-line communication network to the head-end device 34 and then relayed to the respective lighting unit 50 to control that lighting unit 50.

The lighting units 50 may be additionally or alternatively controlled by another device connected to the power-line communication network, such as from computing device 42, or even externally via the internet connection 44 of the head-end device 34. For example, a mobile phone or the like could be used to control the lighting units 50 via a secure internet connection.

Each of the lighting units 50 includes connectors 58 for communication with external devices. Thus, an external device, such as device 42 connected to lighting unit 50b, can be connected and communicate with the head-end device 34 via the wired connection to the lighting unit 50b, and then via the power-line communication network with the head-end device 34.

Additionally, each of of the lighting units 50 includes a wireless communication module. Thus, an external device, such as device 44 connected to lighting unit 50d, can communicate with the head-end device 34 via the wireless connection to the lighting unit 50d, and then via the power-line communication network with the head-end device 34.

In one embodiment, device 44 may be an electronic shelf label 44, or other display device. The label 44 may be battery powered and so may not be connected to the power distribution circuit 10, and hence the power-line communication network. Conventionally, such devices are controlled wirelessly by installing wireless access points across the building. However, this has previously required significant wiring to connect the wireless access points together. By using the lighting units 50 to establish a communications network across the building, it is possible to utilise this network to provide control for additional services, such as controlling label 44.

In another embodiment, device 44 could be a mobile telephone 44 or the like (such as a tablet computer or a barcode reader). Mobile phones 44 often have inbuilt wireless communication modules, for example to connect to Wi-Fi networks. Thus, the power-line communication could also be used to provide basic internet access to users within the building.

In one embodiment, the mobile phone 44 may be configured to utilise a wireless signal emitted by three or more lighting units 50 to determine its location within the building.

As discussed above, the lighting units 50 collect significant amounts of data. This data is periodically transmitted to the head-end device 34 by each of the lighting units 50. This data can be stored on a memory associated with the head-end device 34 or another device connected to the power-line communication network, or can alternatively be transmitted to a remote location via the internet connection 34.

The data can be used for two primary purposes.

Data concerning the operating conditions of the lighting unit 50 can be used to estimate a remaining lifetime of the unit. This information can be useful for determining when a lighting unit 50 is expected to fail. It can also be used to identify when certain conditions are detrimental to the operation of the lighting unit 50. It may be that those conditions can then be changed to prolong the life of the lighting unit.

Data can also be collected regarding the utilisation of the building. For example, occupancy can be determined. This data can be used for automation of the lighting system, for example to deactivate lighting units 50 in unoccupied areas of the building. It may also be used to analyse how the building space is used at different times, for example to identify where improvements in efficiency could be made. Yet further, the data can be used for security purposes, for example to identify occupancy of a room at abnormal times.

Where each lighting unit 50 is equipped with sensors, it is possible to obtain a high sensor density within some situations. This enables, in some circumstances, for very precise measurement of the occupier's location within the space. For example, the data could be plotted visually on a plan of the building to give a heat-map, or the like, showing the location of occupiers within the building. This again has application for both security and optimisation (for example to minimise the distance workers need to travel across a factory floor for frequently-performed tasks).

CLAIMS:

1. A non-domestic building comprising:

an electric power distribution circuit;

a plurality of lighting units connected to the power distribution circuit; and

a head-end device connected to the power distribution circuit,

wherein each of the plurality of lighting units comprises a power-line communication module, and wherein the plurality of lighting units form a mesh network via power-line communication to allow the head-end device to communicate with a target device using the mesh network.

2. A non-domestic building according to claim 1, further comprising:

a controller configured to control each of the plurality of lighting units via the power-line communication network.

3. A non-domestic building according to claim 1 or 2, wherein one the plurality of lighting units is adapted to enable communication with a device that is not connected to the power distribution circuit and/or that does not include a power-line communication module.

4. A non-domestic building according to claim 3, wherein the lighting unit is configured to allow wired communication with the device.

5. A non-domestic building according to claim 3, wherein the lighting unit includes or is connected to a wireless communication module for wireless communication with the device.

6. A non-domestic building according to any preceding claim, wherein at least one of the plurality of lighting units comprises a controller capable of monitoring one or more properties of the lighting unit or its surrounding environment, and wherein the controller is configured to transmit monitored data to the head-end device via the power-line communication mesh network.

7. A non-domestic building according to claim 6, wherein the one or more properties includes a property affecting the operational lifetime of the lighting unit.

8. A non-domestic building according to claim 6, wherein the monitored data includes data suitable for determining occupancy within the surrounding environment.

9. A non-domestic building according to any preceding claim, further comprising:

a non-lighting device connected to the power distribution circuit, wherein the non-lighting device includes a power-line communication module and is adapted to communicate with the head-end device via the power-line communication mesh network.

10. A non-domestic building according to any preceding claim, wherein the plurality of lighting units are connected to a lighting sub-circuit of the power distribution circuit, and wherein the head-end device is separated from the lighting power distribution sub-circuit by at least one circuit breaker or fuse.

11. A method of communication between a head-end device and a target device within a non-domestic building, the building including an electric power distribution circuit, and a plurality of lighting units connected to the power distribution circuit and each including a power-line communication module, the method comprising:

establishing a mesh network via power-line communication, wherein the lighting units act as mesh nodes of the network; and

transmitting data between a head-end device and a target device via the power-line communication network.

12. A method according to claim 11, wherein the target device is a lighting unit and the transmitting comprises transmitting a lighting command from the head-end device to the target lighting unit the power-line communication network.

13. A method according to claim 11, wherein the target device is not connected to the electric power distribution circuit and/or does not include a power-line communication module, and wherein the transmitting comprises transmitting data between the head-end device and a lighting unit via the power-line communication

network, and transmitting data between the lighting unit and the target device via non-power-line communication.

14. A method according to claim 11, wherein the method is a method of communication between a sending device and the target device via the head-end device, the method further comprising:

transmitting the data via the power-line communication network from the sending device to the head-end device for transmission to the target device.

15. A method of monitoring a target lighting unit installed within a non-domestic building, the method comprising:

monitoring one or more properties of the lighting unit or its surrounding environment to determine monitored data; and

transmitting the monitored data to a head-end device using the method of claim 11.

16. A method according to claim 15, wherein the one or more properties includes a property affecting the operational lifetime of the lighting unit.

17. A method according to claim 15, wherein the monitored data includes data suitable for determining occupancy within the surrounding environment.

18. A method according to claim 17, further comprising:

monitoring occupancy in the vicinity of the lighting unit; and

generating an alert when occupancy is detected at a predetermined time and location.

19. A lighting unit for connection to an electric power distribution circuit, the lighting unit comprising:

a luminaire portion for emitting light; and

a power-line communication module for communicating with a power-line communication network, the power-line communication module being configured to establish a mesh network via power-line communication with at least one additional lighting unit connected to the electric power distribution circuit.

20. A lighting unit according to claim 19, wherein the lighting unit is adapted for communicating with another device that does not include a power-line communication module and/or when it is not connected to the electric power distribution circuit.

21. A method according to claim 20, wherein the lighting unit further comprises a wireless communication module for communicating with the target device.

22. A method according to claim 20 or 21, wherein the lighting unit comprises a port or cable for wired communication with the target device.

23. A method according to any of claims 19 to 22, further comprising:

a monitoring portion for monitoring one or more properties of the lighting unit or its surrounding environment, wherein the monitoring portion is configured to transmit monitored data to a head-end device via the power-line communication network.

24. A method according to claim 23, wherein the one or more properties includes a property affecting the operational lifetime of the lighting unit.

25. A method according to claim 23, wherein the monitored data includes data suitable for determining occupancy within the surrounding environment.

26. A method according to any of claims 19 to 25, wherein the lighting unit is a non-domestic lighting unit having a lumen output of at least 5000 lumens.

27. A method of retrofitting a non-domestic building including an electric power distribution circuit and a plurality of existing lighting units connected to the distribution circuit, the method comprising:

removing the existing lighting units;

installing replacement lighting units to replace the existing lighting units, the replacement lighting units each including a power-line communication module; and

connecting a head-end device to the distribution circuit, wherein the plurality of lighting units form a mesh network via power-line communication to allow the head-end device to communicate with a target device via the power-line communication mesh network.

28. A non-domestic building including a power-line communication mesh network, substantially as hereinbefore described with reference to the drawings.

29. A method of communication within a non-domestic building substantially as hereinbefore described with reference to the drawings.

30. A method of monitoring one or more properties associated with a lighting unit substantially as hereinbefore described with reference to the drawings.

31. A non-domestic lighting unit including a power-line communication mesh network, substantially as hereinbefore described with reference to the drawings.

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Claims searched:	1-18, 27-30; 19-26, 31 (partial)	**Date of search:**	3 November 2015

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1-8, 11, 12, 15-27.	David Andeen, "Adding Intelligence to LED Lighting", Maxim Application Note 5383, 22 Mar 2013. Downloaded from http://pdfserv.maximintegrated.com/en/an/AN5383.pdf on 3 Nov 2015. See pages 3 to 6.
X	1, 2, 6-9, 11, 12, 15-19, 23-27	US2014/246993 A1 (CATALANO) See Figs 9A and 9B and paras 73, 74, 83 and 86.
X	1-3, 5, 6, 9, 11-27	US2010/164386 A1 (YOU) See whole document but note in particular Figs 1, 2, 4, 5 and 6 and paras 2, 20-23, 36, 37 and 39.
X	1-3, 5-9, 11, 12, 14-20, 23-27	US2010/237798 A1 (WOLF) See Figs 2, 5A and 6 and paras 22-25 and 29.

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{X} :

Worldwide search of patent documents classified in the following areas of the IPC

H04B; H05B

The following online and other databases have been used in the preparation of this search report

Online: WPI, EPODOC, TXTE, Internet

International Classification:

Subclass	Subgroup	Valid From
H05B	0037/02	01/01/2006
H04B	0003/58	01/01/2006