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SMART LIGHTING SYSTEMS, CONTROLS AND COMMUNICATION PROTOCOLS

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Abstract - Intelligent lighting systems use various methodologies comprising both standard protocols, intelligent methods, control systems and sensors. These protocols define the communication between lighting devices and control systems that many open standards allow interoperability between products from different manufacturers. They offer flexibility and a wide simplified selection in updates and implementations to installed systems. The control systems or transmission means of the protocols have characteristics of efficiency, distance limits and communication speed. They are wired, wireless or a combination of the two (hybrid). This paper deals with a presentation of open communication protocols wired such as KNX, 0-10V, DALI, DMX, BACNET and wireless such as ZigBee, Bluetooth Low Energy BLE. Wired solutions are more stable in terms of efficiency, speed and are not subject to interference, while wireless networks are easily extendable, easily scalable and lower cost. Control systems allow users to monitor and adjust lighting levels, color and other settings. Sensors are used in smart lighting systems to detect and respond to changes in the environment. The various intelligent systems applied to lighting systems can make a significant contribution to safety and energy saving. In fact, energy efficiency is a primary goal, as smart lighting systems use advanced technologies to optimize energy consumption, reduce waste and costs. Safety and reliability are also essential, as intelligent lighting systems offer better illumination, reducing the risk of accidents and improve safety, increasing the safety of people and property.

Keywords - lighting innovations, IoT, lighting service continuity, communication protocols, sustainable lighting

I. INTRODUCTION

Intelligent lighting systems use various methodologies to provide efficient, flexible and customized lighting solutions. These methodologies include both standard protocols, intelligent methods, control systems and sensors. To date, many standard (open) and proprietary protocols have been developed. An open protocol has features published and usable by anyone and allows interoperability between devices from different manufacturers. Therefore, standard protocols are widely used in smart lighting systems to ensure compatibility between different devices.

Interoperability between products from different lighting suppliers offers flexibility and a wide choice to select compatible solutions with simplification in updates and implementations to the installed system. These protocols define the communication between lighting devices and

control systems, allowing them to work together seamlessly. Intelligent methods such as artificial intelligence, the Internet of Things and neural networks are used to improve the performance and functionality of smart lighting systems. These methods allow smart lighting systems to learn from user behavior, environmental factors, and other inputs and adjust lighting levels and patterns accordingly.

Control systems are also a key component of smart lighting systems, allowing users to monitor and adjust lighting levels, color and other settings. These systems can be accessed via mobile apps, voice commands, or other interfaces, giving users flexibility and convenience.

Sensors are used in smart lighting systems to detect and respond to changes in the environment. For example, motion sensors can detect when a room is occupied and turn on lights accordingly, while light sensors can adjust lighting levels based on ambient light levels. Overall, the main methodologies in intelligent lighting systems involve a combination of standard protocols, intelligent methods, control systems and sensors to provide efficient, flexible and customized lighting solutions.

The various intelligent systems applied to lighting systems can make a significant contribution to safety and energy saving. In fact, a luminous flux control system can often offer additional energy savings of up to 20-30%. Smart lighting systems have multiple goals, including energy efficiency, safety and reliability, room design, user comfort, environmental effects, security and automation. Energy efficiency is a primary goal, as smart lighting systems use advanced technologies to optimize energy consumption, reduce waste and costs. Safety and reliability are also essential, as intelligent lighting systems offer better illumination, reducing the risk of accidents and improve safety, increasing the safety of people and property.

The control systems or transmission means of the protocols have characteristics of efficiency, distance limits and communication speed. They are wired, wireless or a combination of the two (hybrid).

Wired solutions are more stable in terms of efficiency, speed and are not subject to interference, while wireless networks are easily extendable, easily scalable and lower cost.

Examples of open wired communication protocols include: KNX, 0-10V, DALI, DMX, BACNET.

Examples of open wireless communication protocols include ZigBee, Bluetooth Low Energy BLE.

With the rapid development of the Internet of Things in recent years, the interconnection of all things will inevitably become the future development trend of intelligent lighting. The choice of technology on which the network is based is wide today and LoRa and NB-IoT are among the most promising technologies in this area.

Long-Range (LoRa) is a long-range wireless protocol that compares to other low-power wireless (LPWAN) or such as narrowband IoT (NB IoT).

Narrowband IoT (NB-IoT) is a particularly versatile and economical IoT and M2M connectivity technology that can be used in the most varied fields.

II. WIRED CONNECTION MODE

Various open standards are available for interior and industrial lighting, among the wired control systems for regulating the luminous flux of devices connected to the network, in addition to presence and illuminance sensors for controlling the LED lights. They can be mentioned the KNX bus, 1/10 V analogue control and the Digital Addressable Lighting Interface (DALI) protocol which allows operation at the on/off level and dimming functions, i.e. variation of light intensity. The DMX (Digital MultipleX) lighting control not only allows to control the dimming but also changes in the color of the light and any movements of the elements carrying the LED light, where provided. The optimal functions of the DMX protocol have been enhanced by using IP-based networks, i.e. over Ethernet cables and via WLAN, which are normally available in various environments.

A. Konnex Control

KNX is a European (EN 50090 - EN 13321-1) and global (ISO/IEC 14543) standard protocol and has three different automatic configuration modes

The A-mode or Automatic-Mode takes up the Plug & Play functionality of the European Home System (EHS) standard, whereby the system self-configures once connected to the bus, since many operating parameters are already preset.

The System Mode incorporates the functionality of the European Installation Bus (EIB) standard and is a freely programmable configuration suitable for processing complex functions. Engineering Tool Software (ETS) allows to program, configure and establish connections between the various network components.

The Easy Mode takes over the functionality of the Building Automation BatiBUS standard and allows to configure the system in a simple and fast way, even if with more limited functions. "Easy Mode" components are pre-programmed but can be partially reconfigured with a manual programming device. In a KNX network it is always possible to make the components of the two modes System Mode and Easy Mode interact.

Furthermore, it is possible to access the KNX system to have central or distributed control via PC, touch-screen display and smartphone using mobile phones and telephone networks or Local Area Network LAN.

The KNX standard provides various transmission means of the wired type (twisted pair TP-0 and TP-1), of the power line PL conveyed wave type, of the radio frequency RF type or on the LAN network.

Konnex adopts the client-server model and uses the network architecture in which the entity that makes service requests is the AC (Application Control) client, while the device that provides a service is the AR (Application Resource) server. A device can be AC and AR at the same time.

B. Analog control 1/10 V

This technology has been one of the simplest systems for regulating lighting fixtures via illuminance or presence sensors. Simply put, the control signal is a direct voltage that varies between zero and ten volts. Two standards are recognized: current sourcing and current sinking. The appliances are turned on and off by acting on the power supply. The regulation of the light intensity occurs via an analogue voltage signal between 1V, corresponding to the minimum brightness level of 10%, and 10V corresponding to the maximum brightness level of 100%.

The 10V control voltage is supplied via a pair of resistors that form a voltage divider that can be replaced by an electronic switch. When the switch is on, the control voltage is close to 0 while when the switch is off, the control voltage is maximum.

The switch is controlled by a PWM (Pulse Wide Modulation) signal, which alternately turns the switch on and off at a rapid speed.

C. DALI Digital Control

DALI (Digital Addressable Lighting Interface) is a protocol used for communication between different control devices, between a control module and light management devices such as power supplies, electronic ballasts, brightness sensors or motion detectors. The manufacturer-independent protocol is defined in the IEC 62386 standard and guarantees the interoperability of control devices in digitally controlled lighting systems, such as transformers and power attenuators.

DALI is a standard technology based on a digital signal capable of uniquely addressing up to 64 luminaires connected on the same bus. In fact, a DALI master is able to control a line with up to 64 devices. Each device can be assigned to 16 separate groups and 16 separate scenes. Cable lengths are limited to up to 300 meters (depending on the conductor cross-section).

DALI uses a two-wire communication system to connect luminaires to a central control device. DALI allows the creation of control groups and the interface with presence and luminance sensors for the control of entire production lines and rooms. All modules can communicate with each other bidirectionally as each one has a unique address, called short address, and groups of modules have a group address. The commands sent on a DALI bus can therefore be addressed to a single module, to a group or to all the connected modules (broadcast).

The DALI protocol is commonly used for manual brightness control and automatic adjustment based on the contribution of natural light. However, DALI allows to

automatically program the switching on, off and regulation of lights with the support of dimmers, quickly locating any faults.

The use of a DALI system facilitates and increases the management of room lighting, giving the possibility of having different automatic scenarios, modifying them with equal simplicity and detecting and solving operating problems.

DALI optimizes flexibility and easily adapts the lighting control also via software without changing the hardware to new conditions, for any change of destination and new configuration of ambientes. Even the lights can be assigned or grouped easily and without intervention on the installation. Furthermore, advanced DALI controllers can be integrated into higher-level control systems and incorporated into whole-building automation systems via bus systems (e.g. KNX, BACnet or MODBUS).

The Configurator for DALI is a standard graphical configuration interface for configuration and is available as a stand-alone Windows application. The Configurator makes functions available for simplified commissioning, configuration, assistance, support and maintenance of a DALI network.

The features that stand out most in the software are a simplified project overview, optimized device addressing, efficient group processing and comprehensive functions for data backup and recovery (Backup & Restore).

D. DMX Digital Control

DMX (Digital MultipleX signal) is a standard digital technology that uses a serial communication protocol to control individual light fixtures or groups of light fixtures. DMX is modular and scalable thanks to the presence on the market of numerous compatible accessories such as amplifiers and signal splitters (boosters and splitters). The DMX system architecture allows to manage up to 512 distinct addresses on the same bus. Each address is characterized by a value between 0 (source off) and 255 (source at maximum level). It is possible to set the address of each receiver (equipment) using dip switches or some types of digital readout devices. Color management therefore occurs by modulating the intensities of the various color components. The success of DMX technology can be attributed to its ease of use combined with its robustness. The cables suitable for connecting DMX devices are in fact extremely resistant to damage and performance degradation.

The high number of available addresses, the multiplicity of their use and the data transmission speed make DMX the protocol suitable for controlling lighting fixtures in complex applications typically created with multi-source LED fixtures (RGB, RGBW, AWB...) and therefore for applications that include RGB, color and light temperature control. RGB lights mix red, green, and blue LEDs (the primary colors of light) to create a wide variety of colors (over 16 million). RGB lights don't have white LEDs, but can still produce a shade of white by mixing red, green, and blue. These lights can only produce one solid color at a time. The acronyms W, WW and IC stand for pure white W, warm white WW and independent controller IC.

For higher applications it is necessary to introduce the concept of DMX universe, i.e. a connection line from the controller to all the devices associated with a same cable. Most recent DMX consoles support more than one DMX universe, each of which must be wired independently.

The DMX protocol is particularly suitable for special LED light effects and for managing lighting as a design element to accentuate particular architectural features and ideal for applications such as stage lighting.

Each lighting fixture compatible with DMX technology is a master-slave system according to a herd logic whereby the lighting controller acts as master and the lighting fixture acts as a slave towards the controller and as a master towards a possible subsequent lighting fixture.

Remote Device Management (RDM), compliant with ANSI E1.20, makes DMX a bidirectional (half-duplex) system, as the controller is able to send a query to networked devices, which can then respond with a response, and introduces additional options for configuring fixtures on the DMX network. In fact, RDM performs multiple main functions such as identification, status and configuration reporting.

Identification allows a control console to automatically detect all devices on the DMX network, distinguished by their DMX address, and determine which of its devices have failed to turn on.

Configuration allows the control console to change the address and other properties of a device. This feature avoids the time-consuming process of manually setting DMX addresses on each fixture. Smart luminaires often have multiple control modes and other settings, which can also be configured via RDM with appropriate software support.

ArtNet is an IP-based protocol for the transmission of DMX information using standard network technologies, both wired and wireless, potentially capable of controlling 32,786 DMX universes (16 million DMX channels), thus eliminating any problems of upgrades and future expansions. Simplifying, at the physical level, Ethernet cables can replace DMX cables, eliminating the need for DMX transmitters given that the signals are sent via an IP port, moreover with bidirectional communication for checkback purposes. Data transfer is managed with UDP (User Datagram Protocol), which allows faster reaction times for data transfers and the detection of any transmission errors. To implement the ArtNet protocol, the node's microcontroller must be TCP/IP-enabled and in the case of direct light control it must be able to generate multiple PWM outputs.

III. WIRELESS CONNECTION MODE

A wireless lighting system represents the optimal solution for renovation projects or adaptation of existing systems where the installation of cables would be expensive in terms of execution times and costs. An exceptional feature

is its scalability, which allows to wirelessly control a single area or larger projects, with thousands of wireless devices. Smart lights have a chip inside them so they can communicate with other devices wirelessly. Each light can connect to an app, a smart assistant or another smart accessory, to control the lights, change their color or control them remotely.

A. Zigbee Control

ZigBee is a wireless communication standard developed with the aim of being simple and economical, in fact, it is one of the most adopted ever, besides Wi-Fi. It is based on the IEEE 802.15.4 specification and operates in the 2.4 GHz radio frequencies. Through the use of small digital antennas of low-power and low-consumption, ZigBee implements a wireless personal area network (WPAN) that requires a low transfer rate and a distance covered up to 100 meters in open field. It is designed for use in embedded applications with tasks known to be performed repeatedly at low cost. In summary, ZigBee allows data transmissions between a central element (Coordinator) and one or more actuator components, devices, sensors (Router and End Device) present in each environment, allowing easy control and monitoring of lighting systems from a central location. It also provides for the (automatic) adoption of master-slave mesh network logics for which the coverage is not limited only to the range of the coordinator but "mesh" of signal determined by the possible presence of multiple "ZigBee router" components powered by the network, even when they are turned off.

B. LIFI Control

LIFI is a newer wireless communication protocol defined by the international standard IEEE 802.15 established since 2011. LIFI protocols are used by LED lighting networks.

The absence of radio frequency and electromagnetic interference, the accurate geolocation feature, the data transmission speed 10 times faster than WiFi, the usability included in the use of the illumination light without installing any specific device facilitate the expansion of this technology to the most varied applications.

IV. COMBINED AND HYBRID PROTOCOL SYSTEMS. A CONTINUOUS-AVAILABLE LIGHTING SYSTEM.

For the purposes of greater reliability of the individual protocols for applications in environments and areas where continuity of the lighting service must be guaranteed, combinations of protocols in active redundancy can be adopted. Undoubtedly, wired controls, despite their installation difficulty and higher cost, offer greater reliability than wireless ones. However, hybrid applications have also been activated that integrate the wireless mode with the wired one such as the wired and wireless DALI application through a DALI wireless gateway. Such a solution makes it easier to carry out extensions of the system.

As a case study, it is summarized a continuous-available lighting system (CAS) in which it is assumed that the components of the system can fail, but that the system is

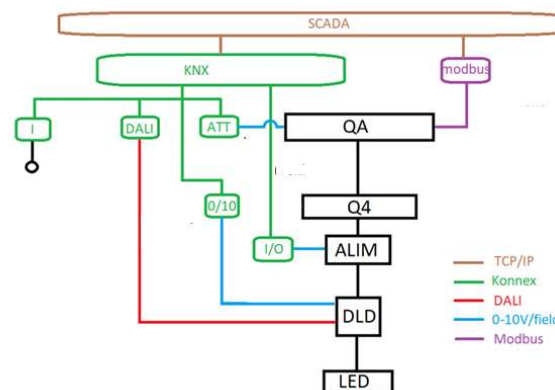


Figure 1 QA general switchboard, Q4 distribution switchboard, ALIM switching power supply ac/dc, DLD controller

still available at the time or period in which its use is required (figure1). To ensure that smart lighting performs its functions, high availability of the required power and high integrity of the power supply and connection structure are required. Its integrity aims to be fault tolerant and to allow a correct maintenance without downtime. The system includes 1000 LED luminaires uniformly distributed across the supply by two independent UPSs and controlled by two wired technologies for the same function. The control types are ON/OFF for 50% of the luminaires and the DALI protocol on the other 50% as the main wired system redundant by the 0-10V analogue system. The lighting regulation is therefore 50% of the luminaires directly ON/OFF with minimum switch-on time, while the other 50% of luminaires allow variable scenarios. The branch distribution is operated in dc current adopting switching power supply ac/dc.

In synthesis, this case study presented concerns a lighting system for an institutional room equipped with an integrated system of control, regulation, supervision and monitoring. The human/system interfaces for command and regulation provided are: - ON/OFF control and regulation push-button panels, - Software dedicated to the lighting system on tablet supports, - SCADA of the systems.

The following communication standards are used:

- Konnex as main BUS;
- DALI for the control of adjustable LEDs via DLD controller
- 0-10V as a redundant analogue system for controlling the LEDs adjustable via DLD controller
- Modbus for the supervision part of the electrical panels
- TCP/IP for high level integration

The DLD controller manages the two digital and analogue control systems, favoring the digital system, and in the event of a fault on this system, it automatically switches to the analogue one.

V. SMART LIGHTING IN STREET AND TUNNEL

A. Street Lighting

The use of control systems for regulating the luminous flux in public lighting is first and foremost a fundamental

concept for reducing energy consumption and no less so for the reduction of light pollution.

The introduction of LED (Light Emitting Diode) has established itself as one of the most advanced and sustainable solutions for improving road safety and reducing energy consumption.

The European standard EN 13201 – Road Lighting – defines the criteria for determining the lighting categories to be applied for the lighting of roads and external areas. The main purpose is to guarantee an adequate level of lighting for the safety and visual comfort of road users, improving visibility and reducing the risk of accidents with attention to energy saving. This design methodology is based on a procedure which, following a risk analysis with which the designer evaluates the influencing parameters, allows the identification of both the design and operational lighting categories.

The lighting class of the streets is determined based on some specific parameters, such as the complexity of the visual field, the brightness of the environment, the type of source used, the traffic flow.

Once the classification has been carried out, the legislation assigns, from a lighting engineering point of view, the minimum values of luminance, illuminance, uniformity and glare control to define, by means of photometric requirements, the Classes of Street Lighting Systems, addressed to the needs of vision of road users and considering environmental aspects.

The exact identification of lighting needs allows to avoid unnecessary waste since, in the presence of reduced traffic flows or in the absence of pedestrians, in specific time slots, it is possible to significantly reduce the lighting. This means that, in the hours in which the traffic can be considered halved compared to the peak periods, it is possible to adopt a lower lighting class, even going down by two classes when the traffic can be considered equal to 25%. Similarly, if lamps with color rendering greater than 60 are used, the class can be lowered even in normal traffic conditions. All opportunities which, if appropriately exploited, allow to reduce energy consumption without jeopardizing people's safety.

In this standard the concept of adaptive lighting was introduced to protect the safety of citizens (Safety) and promote energy saving (table I).

Adaptive lighting is an advanced system and represents the future of safety and energy efficiency in road tunnels. With the ability to adapt to conditions in real time, these systems offer a significant improvement over traditional solution. It is essential to continue to innovate and invest in advanced technologies to ensure safer and more sustainable roads.

Adaptive lighting system automatically adjusts the lighting level based on various factors, such as brightness, traffic and weather conditions. This type of lighting offers several advantages, including greater safety, energy savings and better visual comfort for drivers.

The legislation identifies two different adaptive lighting systems:

- discrete regulation or TAI - Traffic Adaptive Installation, where the operational lighting category is

chosen exclusively by sampling the hourly traffic flow only.

- continuous regulation or FAI - Full Adaptive Installation, where the operational lighting category is chosen through continuous sampling of the traffic flow, but the luminance of the road surface (lighting categories M) or the illuminance (lighting categories C) are also sampled and P) and meteorological conditions.

In summary, FAI lighting systems can control variations in luminance (cd/m^2) and illuminance (lx) over time in relation to traffic volume, time, weather conditions, aging of the road surface.

Using FAI type systems, the standard allows downgrading, associated with the traffic flow, up to 4 lighting categories. The Vehicle Traffic Detection System will be based on triple technology sensors (Radar, Ultrasound and Infrared) which must be installed in a perpendicular position with respect to the direction of travel, one for each lane. They are able to provide the following information:

- Vehicle classification (up to 8+1 Classes)
- Counting of all types of vehicles
- Vehicle speed
- Presence and queue detection
- Measurement of: occupancy, headway and gap
- Stationary vehicles
- Vehicles against traffic.

B. Tunnel Lighting

The lighting of road tunnels represents an important part of the energy consumption of these areas, it is therefore important for environmental and economic reasons and in compliance with safety, to identify which parameters it is possible to intervene on to reduce it.

The design and management of road tunnel lighting require the application of the criterion of a design aimed at the operation of the systems. To this end, it seems appropriate to use flexible and modular configurations of the systems and management criteria that allow operation with programmable electrical power. During service, the luminance at the entrance to the tunnels is generally automatically controlled by sensors, in correlation with the external luminance. It is important to point out that the overall electrical power required by the support lighting system depends both on the luminance must guarantee and on the penetration of its extension. With the same power used, if a decrease in traffic speed compared to the design speed is imposed in critical conditions compared to high frequency ones, which various vehicular signaling systems

TABLE I. PRESUMABLE ENERGY SAVING VALUES OF A FAI TYPE SYSTEM COMPARED TO A NON-REGULATED SYSTEM

Lighting Categories		Levels	Energy
Initial	Final	variation	saving %
M2	M5	4	54
M3	M6	4	54
M4	M6	3	52
MS	M6	2	38

such as variable message signs can communicate to users. Reducing the speed of vehicles makes it possible to reduce the stopping distance and therefore to make available a share of electrical energy to be used with greater density in the entrance area, to make available a higher power density, suitable for critical situations that the legislation general nature cannot predict it.

The objective of regulating the internal luminance is to maintain its value in a safe relationship with the external luminance, so as to always guarantee the speed of the reference vehicle of the lighting design as safe. In the tunnels, the sensors will be organized into two distinct functional blocks defined as the "Local Module", which groups together all the sensors that carry out measurements along the roadway (speed, counting, surface, etc.), and the "External Module", with the sensors which measure the environmental conditions towards which vehicles move in tunnels or which vehicles pass through outdoors.

In this way the complete systems will be composed: for the outside of a Master Module and one or more Local Modules, in relation to the roadways to be controlled and for the internal tunnels, for each direction of travel, of an External Module, placed at the exit of the tunnel, and by N Local Modules, in relation to the length of the tunnel and the installation pace of the local modules.

VI. CONCLUSIONS

This paper presents an introduction to open communication protocols, wired such as KNX, 0-10V, DALI, DMX, BACNET, and wireless such as ZigBee, Bluetooth Low Energy BLE. Wired solutions are more stable in terms of efficiency, speed, and are not subject to interference, while wireless networks are easily extensible, easily scalable, and have lower costs. Control systems allow users to monitor and adjust lighting levels, color, and other settings, and can make a significant contribution to safety and energy savings. In fact, energy efficiency is a primary goal, as smart lighting systems use advanced technologies to optimize energy consumption, reduce waste, and reduce costs. Safety and reliability are also essential, as smart street lighting systems provide better lighting, reducing the risk of accidents, and improve safety, increasing the security of people and property. Intelligent lighting systems implement multiple functions based on the traditional active and interactive action of light to be transmitted as electromagnetic radiation that contributes to safety in movement and the perception of natural and anthropic obstacles and dangers. It is necessary to combine the innovation of components equipped with intrinsic active intelligence with the functional performance of the structures of the overall system, the general objectives of continuity of service, energy saving, protection of health and privacy of people, interactivity, needs of Smart cities and Smart roads.

Intelligent lighting systems use various methodologies that include both standard protocols, intelligent methods, control systems and sensors and allow interoperability between products from different manufacturers. They offer flexibility and a wide selection simplified in updates and

implementations to the installed systems. Control systems or means of transmission of protocols have characteristics of efficiency, distance limits and communication speed.

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