STMICROELECTRONICS SMART STREET LIGHTING SOLUTIONS: REMOTE CONTROL PROTOCOL OVER POWER LINE COMMUNICATION

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ABSTRACT

In a global energy scenario where smart grids are set to enable the transition from the traditional use of electricity to a more efficient and reliable energy systems, by combining efficient energy generation, distribution and consumption with advanced energy monitoring and control, smart street lighting systems are going to be deployed in large scale lighting systems such as city street lighting. Starting from an overview of a smart street lighting system, this article describes the remote control protocol over power line communication for networked street lights. The protocol implementation through an innovative system solution, including the suitable HW and SW tools, is then presented in the last part of the article.

SMART STREET LIGHTING SYSTEM OVERVIEW

In a smart street lighting system, clusters of streetlight lamps can communicate with each other and provide lighting data to a local concentrator which manage the relevant data and send them, often via a digital cell phone modem, to a secure server that captures the data and presents it in web-browser interface.

In addition, a smart street lighting system allows a two-way communication, enabling facility managers to remotely control street lights while keeping track of electrical power consumption in the lamps and in the driving circuits.

Compared to traditional autonomous street lights, monitored street light networks enable reduced maintenance costs thanks to a real-time monitoring of the lamp status and to a more cost-effective maintenance scheduling. Then, in case of fail there is no need of roving inspection. Smart street lighting also assures reduced energy use by dimming or brightening the lights by remote according to a preset schedule or to weather conditions. An efficient collection of data is guaranteed as well.

The primary consumer of smart street lighting is the city, thus energy and maintenance savings allow allocating public funds towards other programs, increasing community satisfaction.

The basic component of a smart street lighting system is the intelligent lamppost which integrates different blocks as follows:

1. Advanced power stages (lamp ballast or driver) aimed to drive the lamps with the highest efficiency;
2. Communication interfaces which allow to built a secure and reliable network, digitally monitored;
3. As option , various smart sensors for monitoring weather conditions, lamppost inclination and air pollution can be included.

A leading provider of complete lighting solutions, STMicroelectronics supports each block with a large portfolio of high performance products and innovative system solutions.

Among the main goals, street lighting has to assure specified value of luminance, illuminance, uniformity and glare according to the road type in order to guarantee maximum visual safety to drivers and pedestrians. That is why highly performing luminous sources, such as High Intensity Discharge (HID) lamps and LEDs lamps are used.

ST's innovative solutions for HID electronics ballast guarantee increased lamp life, enhanced lumen maintenance and lower energy consumption. ST's solutions range from electronic ballasts aimed to drive high power lamps (150W & 250W), to state-of-art-solutions for low & medium power applications (70W & 35W). For powering LED street lights, ST provides engineers with a large solutions portfolio, addressing both isolated and not isolated applications, driving single or multiple LED strings for different level of output power (from 60W to 130 W), specifically designed for outdoor applications.

Most of these lamp driving solutions, both for HID and LED lamps, are based on a digital approach, where a 8-bit or a 32-bit microcontroller assures all the functions needed to drive the lamp and, at the same time, manages all the suitable data for implementing a smart street lighting network.

Moving forward along the key blocks of a smart street lighting system, let's focus on the communication.

Networked street lighting systems can be managed via wired or wireless communications through a number of different communication standards. For the wired option a digital control and monitoring based on power line communication can be implemented. ST's enabling products range from power line transceivers (**ST7540**) to latest generation of power line networking SoC (**ST7570, ST7580, ST7590**) supporting different modulations (B-FSK, S-FSK, B-PSK, Q-PSK, 8-PSK). For the wireless option, the ZigBee technology can be used to build secure and reliable networks. ST's key products enabling advanced ZigBee networks belong to the **STM32W108** series which extends the STM32 family to the wireless connectivity.

In both cases the communication is bi-directional, thus allowing the monitored system to send and receive information and commands to and from the lamp.

Dimming level and turn-on / turn- off command depending on the time of day, on road conditions, or on the natural lighting conditions at the moment can be sent to the lamp. Information on lamp status, energy consumed by the lamp and by its driving circuit, lamppost tilt, etc... can be collected on cluster base and send to a central service center.

The last bock of a smart street lighting system is the smart sensing. As example, the real-time detection of lamppost inclination or fall using a MEMS sensor can be implemented and the **LIS331DLH**, ultra low-power high performance three axes linear "nano" accelerometer, is proposed for the purpose. The key application benefits coming from such smart sensing are the improved road safety and the reduced maintenance cost due to a better schedule of service intervals.

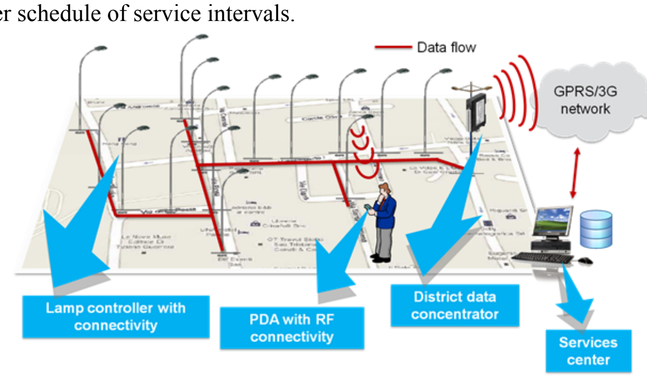

Figure 1: Smart street lighting system

ST PLM NETWORK PROTOCOL

In a street light application the network is composed by several power line modems, called nodes, distributed in the lampposts which hold the illuminators with the correspondent power supply, and one of that node is used as a data concentrator, normally located in the power cabinet which distributes the power to a certain group of nodes, operating in a three phase power line (each device can be connected up to three different power phases). All the nodes and the concentrator share in this way the same power line, which is used as data communication channel (physical means). The concentrator is controlled remotely (via GPRS modem in this application) by a Remote Service Center (RSC), where all the information about the lamps (consumption, status, errors, etc.) and the cabinet itself (ambient temperature, breakers status, etc.) are stored into a remote database. A webserver with a dedicated interface allows the RSC to analyze the data and perform many remote actions, as change the lamp scheduling (on/off/dimming), manually switch on, off or dim the lamps, change the internal time clock of the modems and so on.

The network is logically designed to be a master-slave structure, where the data concentrator is considered as a master device and each node is the slave. Actually any device can start a communication becoming a master, while the target node, each of it having a unique address ID, becomes instead the slave device.

Each node has also an intrinsic capability to be a data repeater, without the needs of any special programming feature, increasing both the reliability of the network and the probability to deliver the information from the master to the slave even in difficult network conditions. The coexistence of more than one master and more repeaters introduces the need of the data collision management, because as more than one device can start the communication at any time, there is the possibility that two devices start the communication at the same time, causing a network jam, lowering the overall performances. The main techniques used to solve this issue are the carrier sense multiple access with collision detect (CSMA/CD), used when an hardware device is able to detect any collision during the data transmission, or the carrier sense multiple access with collision avoidance (CSMA/CA), the one described here in this article, used when the hardware doesn't have this hardware capability.

The implemented conflict avoidance mechanism uses a back-off time and the "band in use" (BU) hardware feature of the PLM to avoid the transmission conflicts. Before starting any communication, each device waits until the band is free by checking its own BU flag. As soon as the band is free, a random back-off time is calculated. Once the back-off time is elapsed, if the band is still free the transmission is started, otherwise the loop is started again (waiting of the BU and new back-off calculation).

The data exchange between all the nodes connected to the same power line uses also a data frame acknowledgement mechanism: in this way the master knows exactly if own transmitted data packed has been correctly delivered to the target node, as for each data frame sent to a target device an acknowledgement frame is awaited (excluding only some particular data frames sent in broadcast by the master).

The repetition feature improves the probability to deliver the data frame to a far target nodes or when the network environment is noisy. As all the other nodes are connected in the same power line, they continuously sense the network catching each data transiting on it. Depending on the device addressing and the data frame/acknowledge flow, each node is able to detect if the sensed frame has to be repeated, discharged or processed. A data identification technique (frame ID) and the forward error correction redundancy (FEC) in the data frames are implemented in order to avoid cyclic repetitions or data loss that can cause the increasing of data traffic.

FIRMWARE CODE AND PC GUI

The firmware implementing the network model previously described is structured by several layers, each one performing different operations.

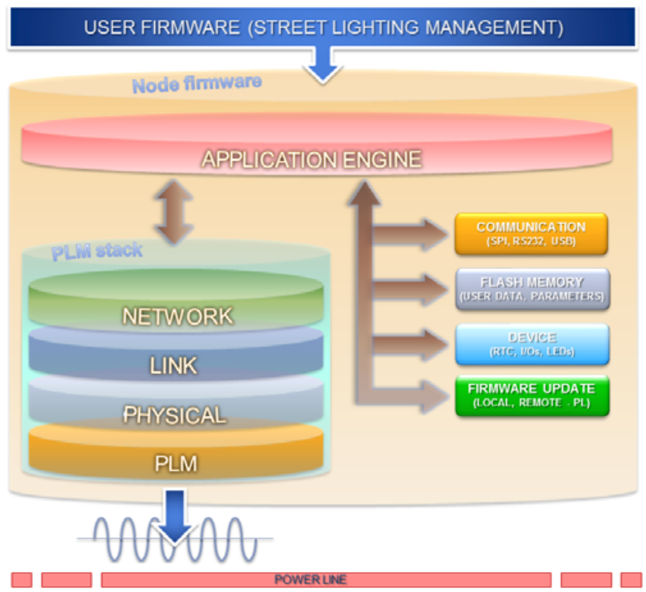

Figure 2: Firmware structure of the power line modem.

The top layer of the firmware is constituted by the user firmware, in this case implementing the street lighting protocol. The state machines for the lamp management which sends and receives commands to and from the lamp power supply (on/off/dimming) are implemented at this stage. There are three types of frame which can be sent to the power line modem: data frames, which contain the user data to send and the parameters read from the lamp power supply (i.e. lamp on, off, dimming, get parameters as lamp power, lamp voltage, ambient temperature, etc.); programming frames, which contain the programming parameters of the node (node unique address, user data to store in the flash memory, etc.); service frames, which contain parameters as well as the PLM stack parameters (timing, data repetitions, etc.), the node time clock, parameters setting the node working model, depending to the network model to implement (with or without acknowledge, broadcast behavior, repetition mode, etc.).

All those frames are managed by the application engine, which is the manager of the information transiting into the node. The data frames containing user data are transferred by the engine from the user level to the PLM stack level. Here the user information is packed and added of the needed information (FEC, cyclic redundancy check - CRC, etc.) and sent to the PLM. Vice versa, as soon as the PLM catch some valid information, these are managed by the PLM stack: the FEC is used to correct wrong data, CRC is checked too and if valid data are decoded, those are sent to the engine in order to be correctly treated and addressed. The PLM stack manages directly the repetitions, the necessary timing and acknowledgements without charge the application engine of this job.

As soon as a data frame is not acknowledged by the target device, each neighbor node which has sensed the transited data frame (and has the repetition feature enabled), after the acknowledge timeout, forwards the data frame (if the band is not already taken by another node). This repetition mechanism, which is managed directly by the PLM stack engine, is done once per each node until the acknowledgement frame is sensed, or until each node has repeated the data frame. The repetition mechanism is implemented also for the acknowledgement frame type (when not received by the master).

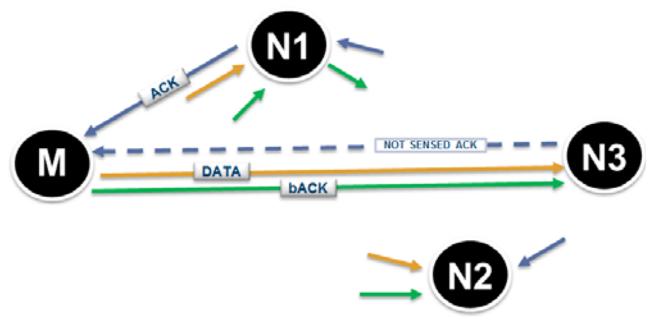

Figure 3: Data communication flow with a case of repetition.

As each firmware layers adds its own information to the original frame, 100 bytes of user data from the application engine become more than double at the power line level, this mainly because of the FEC redundancy added to each byte in order to correct information as soon as arrived to a target node. In this way the network traffic is reduced if the power line is not extremely noisy thanks to the ability of the FEC algorithm to adjust the corrupted information.

Each frame contains also the target address, the source address, some other parameters as a flag byte indicating the network model (flag indicating if the repetition has to be ignored for this frame, if the acknowledge is awaited, etc.), a frame ID avoiding multiple repetitions of the same frame, the CRC (CRC16) bytes, the modem preamble, header and postamble byte, etc.

Another implemented mechanism concerning the repetitions is the hoping. The hop level is one of the PLM parameter that user can define among the service parameters, and is used to assign a certain hierarchy in the repetition. If a frame has to be repeated but the hop level is lower than the one stored in the PLM parameter, the frame is ignored. Normally the hierarchy is set depending on the distance and the ambient noise condition: as close from the concentrator is the node (with repetition feature enabled), as higher is set the hop level, reducing in this way the traffic of not significant repetitions.

The network grouping is also implemented: if this feature is enabled by the user, the first two bytes of any frame address (which actually is 6 bytes long) are considered as the group address. Each frame with the group address different from the assigned group is ignored. In this way it is possible that more than a network can share the same power line without interact to each other.

The current firmware implementation is unique for any kind of device, master, slave or repeater. The PLM stack is able to understand when the master, slave or repeater state machine has to be executed, depending on the data contest.

A dedicated graphic user interface (GUI) is available in order to test or manually manage the street lighting features. Using the GUI the user is able to set all the PLM parameters, to operate on each lamp (addressing directly the target node or performing broadcast operations) as switching on, off or dimming the lamp, or to get all the lamp parameters (lamp status, lamp power, bus voltage, etc.). The GUI runs on a PC and communicates with each node via the RS232 interface. After the programming phase, where each node is set with a unique address, a local database is created and stored in the PC. All the installed nodes are shown in the appropriated list boxes of the GUI.

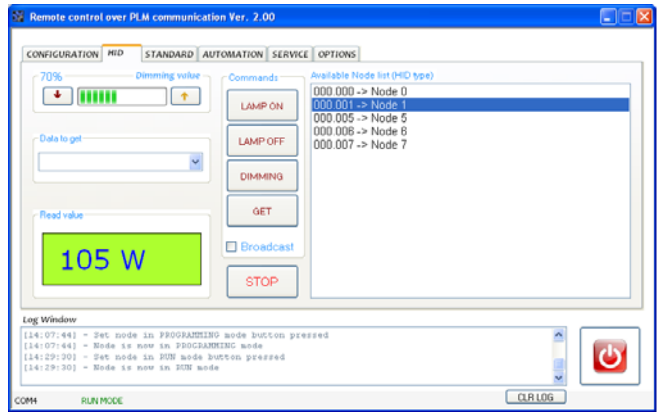

Figure 4: "Remote controller over PLM communication" graphic user interface.

In the HID section the user can perform all the manual operation on each lamp connected to the node shown in the list box, or perform broadcast operations simply enabling the broadcast check box.

A dedicated section of the GUI (Remote controller over PLM communication) allows the user to setup a profile of on/off/dimming operations for a given node, associating to each lamp operation a time clock. Each time the stored clock time is reached (each node has its own RTC clock) the node executes the associated operation on the lamp. Currently up to six steps can be stored and executed in the user data memory of the PLM.

A log window is used to verify the result of each operation done by using the interface, modem results, errors, etc.

More comprehensive information about this ST solution is reported in the application notes AN3046 and AN2451.

STREET LIGHTING HARDWARE BOARDS

PLM dongle node

In the STMicroelectronics solution the PLM node hardware is based on the evaluation board STEVAL-IHP003V1, which has inside the ST7540 FSK power line transceiver and an STM32F103C8 ARM®-based 32-bit microcontroller used for interfacing the PLM transceiver.

Figure 5: STEVAL-IHP003V1, PLM network dongle.

The STEVAL-IHP003V1 is provided with an AC-DC switched-mode power supply specifically designed to match power line coupling requirements, to operate within a wide range of the input mains voltage, and to supply the microcontroller.

The STM32F103C8 performance line incorporates the high performance ARM Cortex™-M3 32-bit RISC core, operating at a 72 MHz frequency, with high speed embedded memories. This MCU thanks his powerful core together his extensive range of enhanced I/Os and peripherals assure all the functionality of the protocol.

The ST7540 is a Half Duplex synchronous/asynchronous FSK Modem designed for power line communication network applications. It operates from a single supply voltage and integrates a line drive and two linear regulators for 5V and 3.3V. The communication speed through the power line is set at 2400bps (it can be increased to 4800bps).

All the main features of the dongle are summarized on the Table 1.

Table 1: STEVAL-IHP003V1 main features.

Modulation	FSK with low frequency deviation
Frequency	132.5 kHz ± 0.2%
Bitrate	2400 bits/s
network building	Plug and play connection
network configuration	Master-slave and peer-to-peer
Node admission	automatic, using ID number
Network address management	selection, announcements and conflict resolution
Operating temperature	0 °C -50 °C

STMicroelectronics' products used in the STEVAL-IHP003V1 are reported in the table 2.

More comprehensive information about this ST solution is reported in the application notes AN3046 and AN2451.

Table 2: STEVAL-IHP003V1 main products.

ST7540	FSK power line transceiver
STM32F103C8	32-bit Microcontroller
ST1S03PUR	1.5A, 1.5MHz Step down switching regulator
STPS2L25U	Schottky diode
ST3232CDR	RS-232 serial interface

Thanks to the serial port this dongle can be interfaced to PC or other boards. In this Smart Street Lighting solution the PLM dongle has been connected with the STEVAL-ILH005V2, an HID lamp ballast, in order to control remotely a lamppost. Diverse of these systems have been used to build a trial network to test the PLM protocol on field controlling more lamps through a PC.

HID Lamp ballast

The ST solution which drives the HID Lamp is the STEVAL-ILH005V2, based on a dual stage architecture: a boost converter (power factor controller PFC) working in transition mode and an inverter composed by a full bridge able to drive 150 W metal halide and high pressure sodium lamps at low frequency square wave.

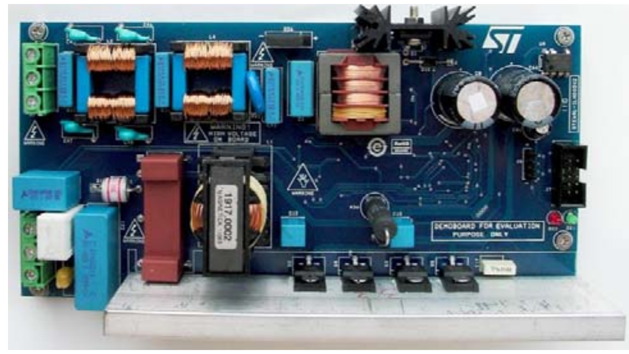

Figure 6: STEVAL-ILH005V2, HID lamp ballast.

All the main features of this lamp are summarized on the Table 3.

Table 3: STEVAL-ILH005V1 main features.

Input range	185 to 265 Vac
Frequency	50 Hz
Rated lamp power	150 W
Dimmable	yes
Average efficiency	90%
Output current Iout	0.38 A
Power Factor	0.99
THD	2.8%
Compliancy	EN55015 compliant

STMicroelectronics' products used in the STEVAL-ILH005V2 are reported in the table 4.

More comprehensive information about this ST solution is reported in the application notes AN3159.

Table 4: STEVAL-ILH005V2 main products.

L6562AD	Transition-mode PFC controller
VIPER16LN	Schottky diode
STGF10NC60SD	PowerMESH™ IGBT
STF10NM60N	600 V /0.53Ω Power MOSFET
STTH1L06	Ultrafast high-voltage rectifier
STTH1R06	Turbo2 ultrafast high-voltage rectifier
L6388ED	High-voltage high/low side driver
LM119	High speed dual comparators
TS272AID	Dual operational amplifiers
ST7FLITE39F2M6	8-bit Microcontroller

CONCLUSIONS

STMicroelectronics Smart Street lighting application presented in this article describes a full system solution to efficiently manage a public street lighting network. It quickly allows to build up own system thanks to provided HW and SW materials (hardware boards are both available in the evaluation board catalogue, whereas firmware code and PC GUI are provided on request).

In ST's Smart Street lighting system, the concept of efficiency involves many important aspects such as energy savings, flexibility on network configuration and management, the remote network maintenance together with a continuous monitoring of network

conditions and status. The system solution is intrinsically scalable, so it can be immediately enlarged to whatever territorial extensions, the latter ones limited solely by the requirements and needs set by the public administrations.
The functional characteristics of each network node and the proprietary implemented data protocol extend the application scopes, going beyond the management of a street lighting network. In fact, the STMicroelectronics PLM node acts like an electronic bridge towards the energy distribution grid and, on the other side, it can be connected with any electronic board, provided with a RS232 port and able to execute basic firmware code allowing user data exchange. Through this bridge, different kind of user information can be transmitted and received allowing to drive and to monitor smart pole for each ambient conditions. The solution described above can be rightly referred as smart pole concept and it naturally find a placing as basic element in the more and more present smart-grid solutions, the latest one constituting the foundation towards the realization of smart cities experimentation.

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