	REMPLI ***NNE5–2001–825*** ***Real-time Energy Management via Powerlines and Internet***

White Paper

REMPLI System Overview

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System Overview

The overall goal of the REMPLI project is to design and implement a communication infrastructure for distributed data acquisition and remote control operations using the power grid as the communication medium. The primary target application is remote meter reading with high time resolution, where the meters can be energy, heat, gas, or water meters. The users of the system (e.g. utility companies) will benefit from the REMPLI system by gaining more detailed information about how energy is consumed by the end-users. In addition, they will have more information about the status of the power grid and they will be equipped with means to remotely terminate supply of energy, if this is required (e.g. in pre-paid systems). Based on the availability of fine-grained energy consumption data at the end user's site, the energy flow can be better controlled and leakage can be detected more efficiently. Finally, energy billing and energy management are high-level services that can be built on top of the REMPLI system.

The basis of the REMPLI system is a powerline communication (PLC) infrastructure that allows to access metering and control equipment remotely. In according with the overall project goals, the primary usage of this infrastructure is remote meter reading and remote control. Besides that, the communication platform is open to various kinds of add-on services. Schematic architecture of the communication network is illustrated in Figure 1.

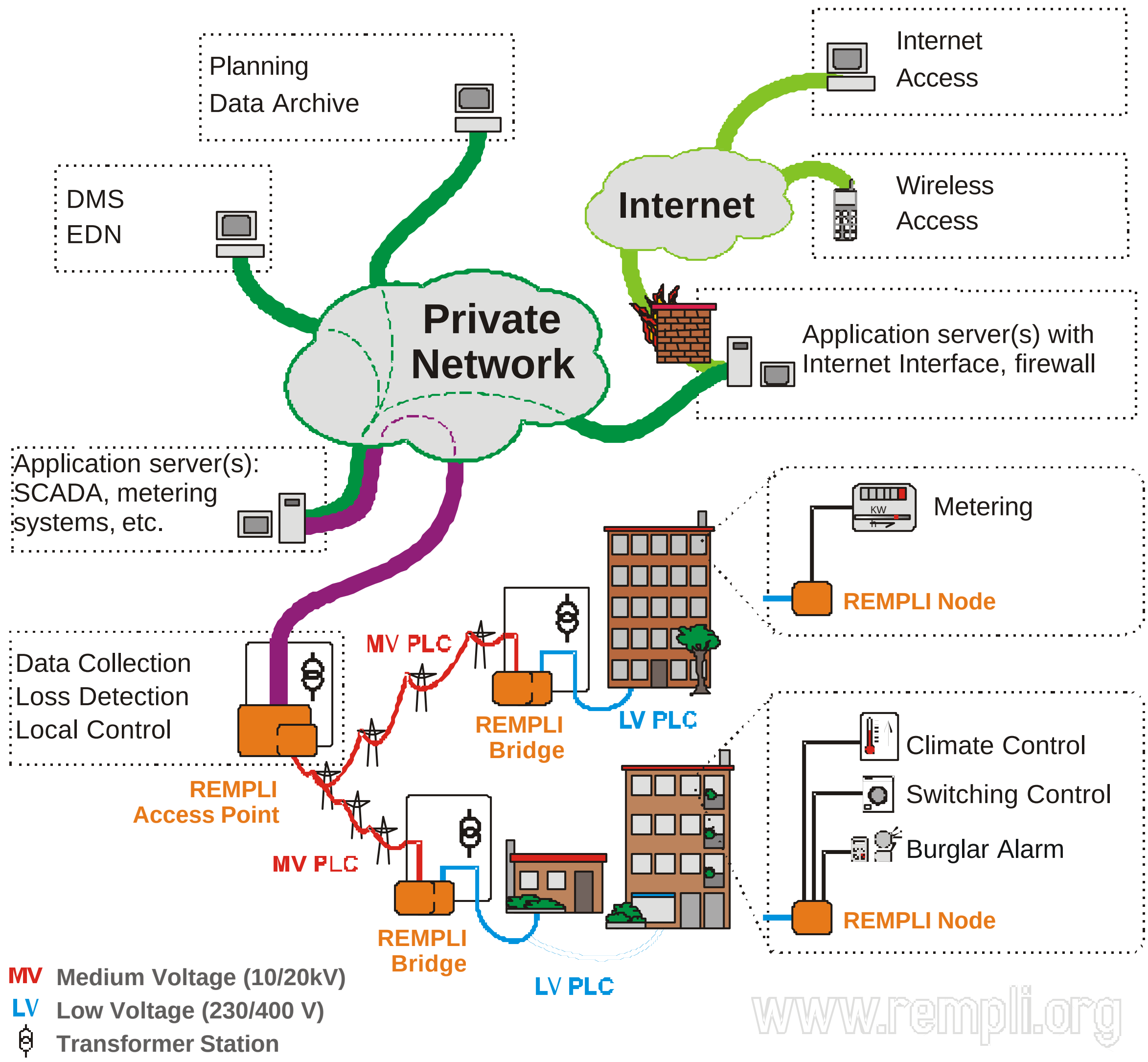

Figure 1: REMPLI system architecture

As shown in the above figure, the REMPLI communication infrastructure consists of

- low-voltage segments (blue lines), which cover groups of energy consumers (for example, a segment can span across one staircase of apartments within a living block, or cover a single production branch);
- medium-voltage segments (red lines) between the primary and secondary transformer stations;
- TCP/IP or IEC 60870 based segments (thick purple lines) between the primary transformer stations and the Application server(s);
- TCP/IP communication (green lines) between the Application Servers and their clients. The interfaces provided by the Application Servers could be available only within the Private Network or also by Internet clients (e.g., SCADA server/client communication).

The bottom-level of the communication infrastructure is comprised of **REMPLI Nodes**, each coupled with a PLC interface (usually a low-voltage PLC slave, in certain cases also with medium-voltage PLC interface). A Node is usually installed at the consumer site, e.g., inside an apartment, and has a number of metering inputs (such as S0, for electrical energy meters). Nodes are also equipped with digital outputs that allow switching off and on electrical/heat/gas/water supply for a particular consumer, upon commands from the utility company.

At the top-level of the infrastructure is the **REMPLI Private Network** (typically TCP/IP-based), where Application Servers of utility companies are connected to. Every Application Server performs a certain dedicated function, such as metering, billing or SCADA. Special Application Servers can also offer access to data, collected and processed by the REMPLI system, to clients, located in the open Internet, or even to wireless terminals. All Application Servers access Nodes in the PLC network via **REMPLI Access Point** – a device which interconnects TCP/IP and PLC-based segments and, optionally, implements a number of additional services.

The software architecture of a Node allows for running different kinds of applications, each provided with an interface to the PLC environment. Any application running at the Node is “visible” on the other side of the communication system. Hence Application Server(s) can access data collected by a Node application (e.g., retrieve metering values) or provide inputs into the application (configure the application itself, or control peripheral devices – such as relays – via the application).

A powerline network can contain other PLC nodes (i.e. non-REMPLI) as well, not represented in the picture. These nodes are equipped with the same type of PLC interface as REMPLI Nodes; however, they run different software and perform different functions, sharing the available PLC bandwidth with the REMPLI communication infrastructure. The REMPLI system will co-exist with them, though not providing any facilities for communicating to foreign devices.

All Nodes within a REMPLI installation are connected to a cascaded powerline network. The powerline network consists of one or multiple Low-Voltage and one Mid-Voltage segment. Communication at both levels is Master/Slave-based. Low- and Mid-Voltage segments are coupled by the **REMPLI Bridge** which is installed at the secondary transformer station, between two parts of the cascade. Physically the Bridge is comprised of an interconnected high-voltage PLC slave and a low-voltage PLC master. The link, established by a Bridge, is transparent for the information flow: requests are simply forwarded from the upper part of the cascade into the lower one, responses are passed back. Hence, the whole PLC network of two segments becomes a single Master/Slave communication environment.

In some installations, where a utility company needs to collect information from the secondary transformer station itself or to control it, the Bridge can be combined with a Node. It is also possible to equip a secondary transformer station only with the Node, and not with the Bridge. In the latter case, the transformer station becomes a communication end-point, and no data transmission occurs in the Low-Voltage segment. The Node here is connected directly to the Mid-Voltage network over a corresponding PLC slave device.

Communication Architecture

The principal architecture of a Node-Access Point communication is illustrated in Figure 2. This structure can be logically divided into three major subsystems: the **Access Point Application**, the **Node Application** and the **Powerline Communication System**.

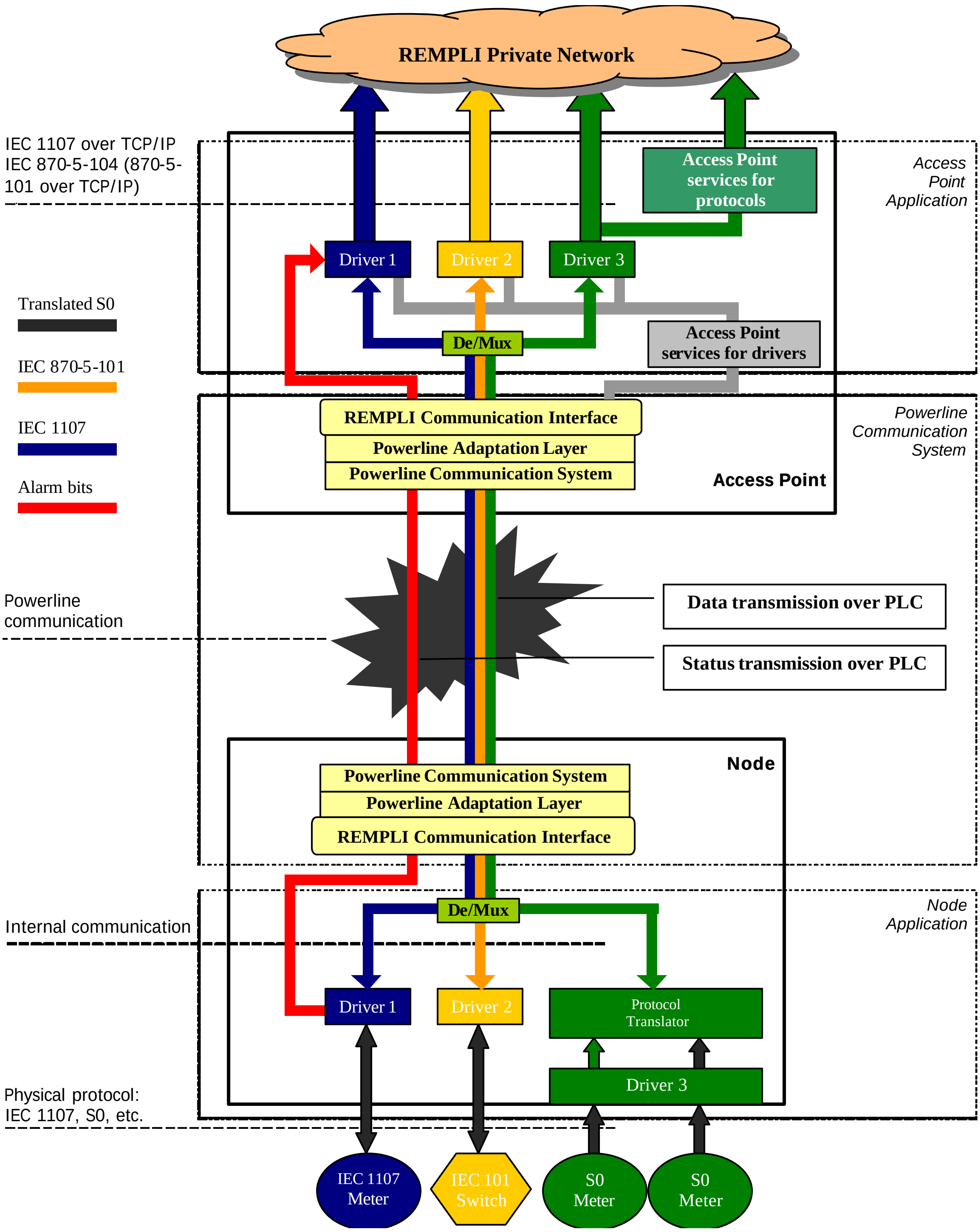

Figure 2: REMPLI communication architecture

Metering and control devices, located at the bottom, are capable of communicating using a certain protocol, such as IEC 1107 and M-Bus (for metering) or IEC 870-5-101 (for SCADA). Application Servers (not shown in this picture) are connected to the REMPLI Private Network segment. While performing their dedicated tasks, Application Servers expect to communicate with the underlying metering/control hardware using the aforementioned protocols, as if the devices have been connected directly.

The REMPLI communication system therefore is based on the idea of *tunneling particular metering/SCADA protocols over the powerline network*.

At the Node side physical connection to individual metering and control devices is provided by **drivers**. Every driver is dedicated to a particular combination of hardware interface / communication protocol. A single driver can handle several pieces of homogenous equipment (shown for the case of S0 meter in the picture above).

If necessary, a driver can also perform certain processing of metering data (for instance, store it in a log directly at the node; re-calculate raw measurement data into valid physical units; etc.). Often, drivers also attempt to reduce the amount of data transmitted over communication network (for example, compress metering data). This, of course, requires support from the driver at the opposite side – the Access Point side. Also in some cases, due to legal limitations related to certification of the system, drivers are not allowed to modify application data (or even complete protocol PDUs), transferred over the communication system.

Some data, such as that coming from an S0 interface (pulse input from meters), can not be transferred over the PLC directly. It has to be translated into a full-fledged communication protocol, understood by metering software on the other side of the REMPLI system (e.g., IEC 1107). This is performed by means of a **protocol translator**, which is tightly integrated with the driver[1].

At the Access Point side drivers perform a different function: they convert a metering/SCADA protocol, received from the Node, into its TCP/IP-based equivalent. This can be either simple tunneling or conversion from one standard into another (for instance, IEC 870-5-101 has to be converted into IEC 870-5-104). All deviations from standard, implemented at the Node side driver to reduce traffic over the communication network, are undone here: above the Access Point (just like below the Node), each tunneled protocol is fully standard-compliant.

The Powerline Communication System is a set of hardware and software components that implement data transmission over a single-segment (Medium Voltage) or dual-segment (Medium- and Low-Voltage) powerline networks. Internally the Powerline Communication System comprises a number of layers (transport, network and physical). It handles packet-oriented driver-to-driver communication. Most of this communication is carried out using PDUs (Protocol Data Units) of the respective metering/SCADA protocol, typically in a master/slave way: a request is issued by an Access Point side driver and responded by a Node side driver. Apart from data communication, the PLC system, used within REMPLI, also offers another technique: fast status transmission. This allows for fast signaling (sending several bits, always in direction from Node to the Access Point), and can be optionally used for internal driver-to-driver communication.

Besides Powerline, the Access Point architecture allows for transmitting data over different communication systems (such as ISDN, GSM or plain old telephone system – POTS). However, the primary focus of REMPLI is the PLC.

[1] Support for S0 metering devices will not be implemented within REMPLI, since the target field-test sites are equipped only with IEC 870-5-101 SCADA devices, IEC 1107 and M-Bus meters. However, software architecture is such that it allows for integration of support for S0 meters later on.

Software Architecture

As shown in Figure 2, the communication path through the powerline network is on both sides (Access Point and Node) terminated by two component blocks: the **Powerline Adaptation Layer** and the **REMPLI Communication Interface (RCI)**.

“Adaptation Layers” (Powerline Adaptation Layer, ISDN Adaptation Layer, etc.) are introduced in order to unify interfaces to various communication mediums – different versions of the powerline communication system, ISDN, GSM and so on. No matter which technology is used to access target nodes, the REMPLI Communication Interface remains the same. Transition between the REMPLI Communication Interface and the PLC system is carried out by the Powerline Adaptation Layer.

The REMPLI Communication Interface is available both at the Access Point and at the Node (used, respectively, by the Access Point and Node applications to exchange data with each other) and comprises the following functionalities.

- Delivery of arbitrarily-sized PDUs from the Access Point to a single or multiple Node(s) and the other way around. Two different communication styles are provided: reliable (upon delivery failure, the communication system performs several re-transmission attempts and returns an error if they all fail) and unreliable (if a PDU can not be transmitted, the error is ignored). Data transmission from the Access Point can be unicast, multicast or broadcast; data transmission from the Node is always broadcast (or unicast, if only one Access Point is connected to the network).
- Concurrent transmission and priority management. On behalf of Application Servers, Access Point Drivers can submit multiple concurrent PDUs to be transmitted to different (or the same) Node(s). Each PDU has a priority class associated with it. Whenever a higher-priority PDU is received, it is transmitted to the destination Node before any lower-priority PDU, even if transmission of a PDU is already in progress (the latter one is temporarily suspended, if necessary).
- Fast status information transmission. This service allows every Node to set a bitfield of a limited size (a few bits), in which all changes will be quickly propagated to the Access Point. This service is asymmetric: Nodes can only modify their status bitfield, while Access Points can only receive status information. In case of PLC the fast status transmission mechanism is available natively; in other communication networks it is emulated by a respective adaptation layer.
- Network discovery. Communication system is able to report which nodes are currently available in the network. This information is used by the Access Point Application to detect potential problems with Nodes and to re-route packets via other Access Points (in case multiple Access Points are used to manage different communication paths – like in case of a meshed/switched PLC network).
- Point-to-point connection management. Some communication systems, such as ISDN or analogue telephony (POTS), require establishing point-to-point connections to target Nodes (dialing numbers) before communication becomes possible.

The primary purpose of an **Access Point driver** is to communicate, on one side, to the corresponding **driver of the Node Application** and, on the other side, to one or more **Application Servers** connected to REMPLI Private Network. In order to operate, drivers require a set of common functions, some of which involve communication to Nodes. For example, a driver shall be able to determine, whether its “sibling” is available at a given Node or not. Besides, some functionality available via the REMPLI Communication Interface (e.g., network discovery) requires a higher level of abstraction than offered by the RCI. This functionality is combined into the separate software module – **Access Point Services for Drivers**. Other functionalities of this module can be used to perform various network and node management operations that are common to different communication mediums. For example, this component is responsible for performing software updates at the Nodes.

As mentioned above, a communication system such as PLC offers packet-oriented communication, where each PDU is independently addressed and delivered to a certain REMPLI Node. Apart from that it is necessary to address individual drivers at the Node and at the Access Point. This additional addressing information is introduced at the layer above RCI – inside **De/Multiplexer**. The De/Multiplexer component performs multiplexing and de-multiplexing of communication streams between different pairs of drivers. In case multiple Application Servers on top of the Access Point “speak” the same communication protocol and connect to the same driver, De/Multiplexer also helps driver distinguish, which incoming response PDU shall be routed to which application (request/response identification facilities). Finally, De/Multiplexer component at the Access Point is responsible for handling communication path switching and redundancy: if a packet can not be delivered to a target Node directly from this Access Point, it can be re-routed to another Access Point which will handle the delivery. Usually, this process is transparent to drivers, unless the communication protocol, which is handled by a particular driver, includes link control facilities. In the latter case a driver can obtain information about availability of Nodes in the REMPLI network behind this Access Point and forward this information to Application Server software.

The PLC-based communication platform, designed and implemented by REMPLI, is highly versatile and can be easily extended to support different applications. The network provides a variety of services to transmit any kind of packet-oriented data. All interfaces to the communication system are standardized and unified both at the Access Point and Node sides. The system itself does not impose any requirements on the data transmitted; therefore, support for a yet another communication protocol can be easily added through developing an additional pair of drivers (one running at the Node, one at the Access Point). The REMPLI communication infrastructure will handle packet delivery, manage redundant and switched communication paths and offer a set of other services that ease development and deployment of such drivers.