Radiofrequency Interconnection between Smart Grid and Smart Meters Using KNX-RF and 2.4 GHz Standard Protocols for Efficient Home Automation Applications

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***Abstract*—**Smart grids have attracted considerable interest in the research community and among market actors. The main interest of smart grid is to continuously monitor the whole system energy and optimize it in order to increase the overall energy efficiency. To this purpose, a power energy manager like Linky (ERDF project - France) is needed to ensure the exchange of control and sensor information between the smart grid network and the smart grid end-device equipment within the house. This paper gives a full understanding of the Linky meter that operates under a two-way efficient radio home automation protocol: KNX-RF (868MHz) and ZigBee (2.4 GHz). In this context, the paper presents a study over the KNX-RF protocol with respect to the ZigBee protocol in terms of range, consumption, robustness and configuration. It also provides a study of a typical use-case scenario including Linky smart meter.

***Index Terms*—**Radiofrequency, smart home, smart meter, smart grid network, energy management, KNX-RF, ZigBee.

I. INTRODUCTION

The aim of this paper is to give a full understanding of the behavior and overall RF benefits of the intelligent management of smart electricity distribution network throughout smart meters such as Linky (ERDF project - France). In fact, this work mainly concerns the Linky smart meter, which is equipped with a standardized bi-protocol transmitter KNX-RF (868 MHz) / ZigBee (2.4 GHz).

From upstream point of view, it has been shown in [1]that an intelligent management of electrical network power from the supplier side, especially in case of high-consumption equipment (heating, cooling, hot water tank ...) at periods of peak demand for electricity (periods of high price and/or stress, usually in the early evening where operators need more generating capacity–including more costly "peaking" units) would allow to optimize the actual needs for energy with multiple suppliers. This represents an important challenge since the storage of electrical energy is tricky and requires the use of convenient new technologies. Adapting the need for electrical power to applications and user demand would limit excessive draw of power from the electrical power plants on the grid, thus avoiding power waste at the source.

Furthermore, the upstream optimization of energy consumption would also have a downstream effect towards the end user if the electrical network consumption is optimized: less overall consumption, adaptation of the technology-producing type and a highlighted ecological footprint.

However, to accomplish this, it is necessary to work on the whole chain: electricity production, primary adjustment levers, up to the possibility of intelligently optimizing the actuated energy consumed by the end devices and equipment powered by 230 V (Europe) within the house (heating, HVAC, lighting, ...). This link between the supplier and the connected objects is ensured by a smart meter like Linky [1].

Linky ensures the interaction between the electricity management of the residential area and the actuators in the house by providing the necessary data. It is therefore an intelligent gateway between the smart grid and smart home. For more convenience, the Linky meter must be equipped with a radio transmitter to transfer network information to the house and therefore to the home devices capable of managing energy. It is hence important that the meter integrates an RF home automation protocol adapted to its environment "energy supplier" and to the conditions (location in the house, in the street, etc.). Yet, there is no wired or wireless common protocol that ensures the transit and management of data from the power grid to the end device inside the house. In addition, these new facilities have to cope with the plethora of existing home automation protocols, the market not being driven by a unique communication protocol. That is why the smart meter was made to integrate a transmitter with two transceivers, respectively with two standardized radio protocols: Sub-1 GHz KNX-RF protocol and 2.4 GHz ZigBee protocol, which best represent the professional European market of efficient smart home today [2]-[3]. Other protocols like EnOcean, Zwave, etc. present some

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weaknesses on a technical and market point of view to be integrated into the meter for this sort of applications [4]-[6].

In the literature, the energy management of a residential area standing the supplier vision and the management of smart grid communication has been published many times and only one single paper was published on the Linky project [1]. Also, on the ZigBee Smart side, there are several descriptions[7]-[10].The paper [11] presents an overview of the RF performances for several RF communication protocols (ZigBee, KNX-RF Ready, Bluetooth…) with scenarios including smart-meters as a node in the system based on a physical layer analysis. In order to complete the literature, this paper presents for the first time the overall link between energy distribution and the data communication mode including the transport to the home radio end devices, as well as the efficiency of the overall system protocol when comparing the performances of the new Sub-1 GHz KNX-RF "Multi" standard at 868 MHz to ZigBee at 2.4 GHz. This study shows the global performances in terms of RF range, DC and AC consumption, robustness, configuration and radio media occupancy with dedicated and realistic scenarios, including the e-meter "Linky".

In the first part of this work, the Linky meter equipped with a dual-protocol transmitter (KNX-RF Multi 868-870 MHz and 2.4 GHz ZigBee) and its environment (France electricity network) will be described. The possible exchange modes between the meter and the end-devices will be presented. Then, after a description of KNX-RF Multi and ZigBee protocols, the paper will expose some system examples of interaction between the smart grid equipment and the smart grid network through the smart home manager(s) of energy.

In this context, the performances of the protocol KNX-RF Multi in terms of radio range, system energy consumption, configuration, interoperability (past-present KNX-RF: Ready, Multi, cross profile interactions ...) will be discussed, particularly with respect to the 2.4 GHz ZigBee radio systems performances, both protocols being complementary to one another

In a typical use-case of the power management box Linky, a proposed home automation scenario is detailed that allows determining the impact of radio traffic in the house (about 60 products in Linky Fast mode of KNX), the potential collisions between protocols in the same frequency band and the overall consumption of the system during the standby mode.

II. Description of Smart Grid System with E-Meter Linky and the RF Systems Based on KNX-RF and ZigBee

The electromechanical or electronic current meters do not respond to changing needs. A European Directive states that 80% of electricity meters should be communicating by 2020 to promote competition and energy efficiency and enhance the management of electrical networks. This is why, since 2006, France Electricity Distribution Network (ERDF) is developing a project for a new electricity meter called "Linky" for low voltage consumers (≤ 36 kVA). Linky is a remotely configurable and communicating meter, capable of storing and conveying information upstream (distribution network managers, suppliers, etc.) and downstream (customers, energy service providers, etc.). It supports two key functions: measurement-setting-metering function and control function. Linky can bring different benefits in the short and medium term, directly or through the addition of complementary equipment:

- Interventions and meter readings are made by the network manager without moving, they are hence made more rapidly and without the need for the presence of the customer.
- The information collected will allow electricity suppliers to propose adapted and innovative pricing offers.
- Linky will facilitate network operations through the knowledge of electrical consumptions and the integration of renewable energy. It is a technological brick that enables to evolve in long term towards Smart Grids.
- Finally, the end customer might benefit from richer and more frequent information on his consumption and / or production of electricity.

The smart network integrating the Linky system for electrical energy management is depicted in Fig. 1 where the interaction between the various smart grid actors is described [12].

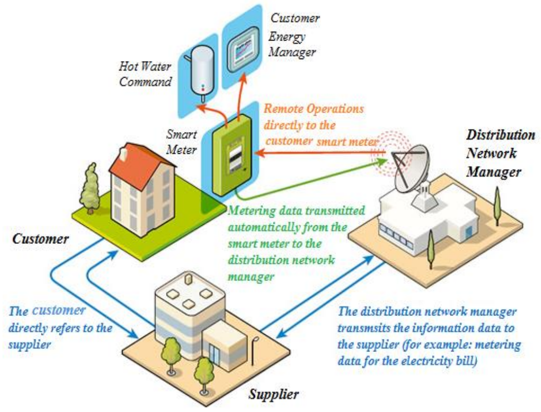

Fig. 1. Smartgrid network with the e-meter [12].

The reduction of energy expenses related to Linky meter is estimated to be between 5 and 15% by ADEME (France national agency of environment and energy management). This energy savings can eventually be applied through an energy manager which centralizes the management of devices such as electric heating, heat pumps, air-conditioners and hot water tanks (Fig. 2). It thereby allows users to always be informed about their electricity consumption and cost (current and future) and it can possibly relieve an electrical circuit depending on the current fare.

The central energy manager and/or the home equipment (non-centralized or centralized by a home automation box) are linked to the smart Linky meter using a two-way radio protocol (KNX-RF Multi Fast profile, and ZigBee) [13]. In fact, a device named Linky Radio Transmitter (LRT) supporting the two protocols, whose function is to provide the information transmitted via the customer Tele-Information (TIC) to downstream equipment and listen to the periodic input requests for reading specific data from downstream devices, can be plugged into the Linky smart meter.

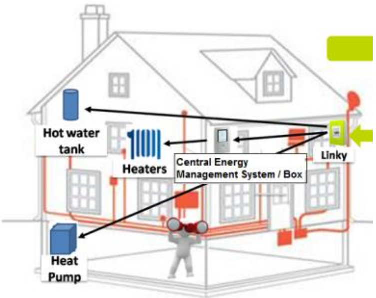

Fig. 2. Smart home environment connected to the smart grid with the e-meter Linky.

A remote control to make the associations in the configuration process between the LRT and the downstream devices is supplied with the smart meter (Fig. 3). The exchanged radio telegrams during the association process are encrypted with an installation code. All the frames exchanged between the LRT and the downstream devices must also be encrypted.

In order to support the two protocols, the LRT integrates two radio transceivers operating at 868-870 MHz and 2.4 GHz respectively for KNX-RF and ZigBee, which represents a complementarity in the home automation professional market. The profile KNX Multi "Fast" is used to actuate devices powered by 230 V main but it could also be possible to use KNX Multi "Slow" in order to communicate with a battery-powered device and display the information coming from the smart meter and the smart grid.

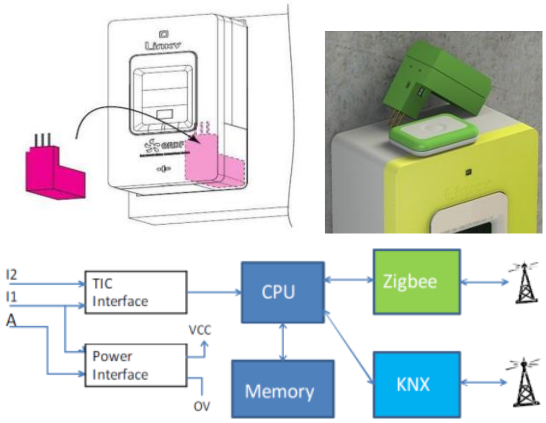

Fig. 3. Architecture of the linky radio transmitter.

A Central Processing Unit (CPU) implemented in the LRT is used to translate the TIC data to the KNX-RF and ZigBee communication format. The LRT must implement the following specific characteristics in CPU:

- Ability to detect the TIC physical layer with Linky meter,
- Ability to memorize the address of the meter received and read on the TIC message,
- Ability to manage ZigBee and KNX communications at the same time (emissions on KNX-RF and ZigBee channels as simultaneous as possible, reception on ZigBee and KNX-RF channels simultaneous mandatory, emission should not interfere with the reception),
- Ability to store data and a minimum of 20 links,
- Ability to upgrade its own software,

Besides, the LRT must respect the human environment, by emitting the lowest possible radio wave. To achieve this, all data are not sent at each cycle. Indeed, a group of specific data is sent for each LRT Sending Data Mode: on request, on power on, on update, on configured demand and on alarm reception.

The LRT must send requested data to interested devices using their associated protocol (KNX-RF or ZigBee, depending on the device). In terms of emission period, it can be configured for each data and for each intended downstream device. For the same data to be sent to different equipment, if there are several sending periods defined, the shorter one is used. In terms of data format, the tele-information TIC data are encoded with a "binary to hexadecimal ASCII codes" format. They must therefore be decoded before being sent to downstream equipment.

III. Description of the RF Protocols

A. *Standard Protocol: KNX-RFMulti*

The LRT uses the "Fast" operating channels of the KNX-RF Multi version. This is because the downstream devices concerned with energy efficiency are main-power electrical devices. However, the central energy manager which can be a multi-protocol home automation box can also manage battery-powered devices through the *"Slow"* channels of KNX-RF Multi in order to create connections to products which use battery, for the visualization of data for example. The advantages of using a box connected to the internet network with a LAN is to provide information to the final user by internet access out of the residence or a Wi-Fi connection in the house with smart phones, tablets, computers.

KNX is a standard dedicated for Home & Building automation applications and the world's first open standard that complies with ISO/IEC 14543-3, CEN EN13321-1/2, CENELEC EN50090, also GB/ZB20965 for China and US ANSI/ASHRAE standard 135 [2]. KNX was initially defined for wired solutions and later extended to wireless communication (KNX-RF). KNX-RF is a green technology suitable for wireless sensor networks as it enables smart home and building automation systems to reduce their energy consumption, manage lighting, blinds and shutters, heating, air conditioning controls, security, and remote access with supervision capabilities. Looking past, the first KNX radio specification, version 1.1, was updated in 2010 and named KNX-RF Ready. It introduced a push-button configuration mode and operates at a unique frequency of 868.3 MHz. It used a Manchester channel encoding and a 2-FSK modulation with a deviation of 48 to 80 kHz (typically 60 kHz). It had a chip rate of 32.768 kchip/s.

In 2011, KNX-RF Ready was extended to a new standard named KNX-RF Multi, which added redundancy and increased reliability and allows a bidirectional communication. Some features of these two standards are shown in Table I. As mentioned earlier in the introduction, the KNX-RF module implemented into the home box must ensure compatibility between Ready and Multi devices.

The latest version Multi of KNX-RF standard implements a number of robustness mechanisms which prevent the system from being disturbed. KNX Multi standard enables switching between five radio channels, thereby allowing agility. These channels are divided into two main categories. The first category consists of three "Fast" radio channels (Fast F_1, F_2, F_3) with a chip rate of 32.768 kchip/s. The second category comprises two slow radio channels (Slow S_1, S_2) with a lower rate of 16.384 kchip/s (Table I). The different channels in each category are used in frequency agility. In case of group communication, if one or several acknowledgements messages (Fast-ACKs) are missing, the device retransmits the frame again but on a different radio channel. The acknowledgement mechanism stops after 3 successive immediate. A typical sequence would be F_1, and retries on F_2, $F_3$and F_1. The same applies for Slow radio channels with S_1 and S_2.

TABLE I: PHY SPECIFICATIONS OF KNX-RF CHANNELS

Channel Name	Frequency (MHz)	FSK Frequency Deviation (KHz)	Chip Rate (Cp/s)	Preamble Length (Bit)
Ready	868.300	60 (48-80)	32768	76
F_1	868.300	60 (48-80)	32768	247
F_2	868.950	60 (48-80)	32768	247
F_3	869.850	60 (48-80)	32768	247
S_1	869.850	20-65	16466	4111
S_2	869.525	20-65	16466	4111

"Fast" channels are intended for systems requiring a fast reaction time (about 42 ms) between the transmitter device and the actuator device i.e. lights and shutters. As for "Slow" channels, they are intended for systems that do not have a critical response time (e.g. heating control) and include devices that implement a Non-Permanent Reception Mode (NPRM) with a reaction time of about 500 ms. The NPRM devices sleep when not scanning for KNX packets in order to reduce the energy consumption. This enables them to be battery powered. It allows getting products with a battery lifetime from 2 up to 7 years with classical battery technologies (heating valves, thermostats, sensors…).

B. Standard Protocol: ZigBee 2.4 GHz

ZigBee is a wireless standard maintained by the ZigBee Alliance [3]. Its lower layers are specified in the IEEE Wireless Personal Area Network standard 802.15.4. The upper layers are specified by ZigBee Alliance standards, but other stacks based on IEEE 802.15.4 are available, such as the IPv6 adaption 6loWPAN. ZigBee is designed as a mesh network, allowing a class of node called full-function devices to serve as network routers for Multi-hop networking. This allows devices to interact with other devices outside of their direct range. One of the routers serves as a coordinator, which takes a central role in the network. Reduced-function devices cannot be routers, making them suitable for battery-powered operation. Different physical layer specifications allow for operation in different frequency bands. Most ZigBee devices use the 2.4 GHz band with its higher data rates and because it is a worldwide frequency. A transmission mode at 868 MHz is available for sub-GHz communication in Europe, however due to low data rate and limited support, it is not widely used. The 2.4 GHz ZigBee is based on the 802.15.4 PHY, which uses Offset-QPSK modulation and Direct-Sequence Spread Spectrum to achieve a data rate of 250 kbit/s. Four bits are encoded as one of 16 32-chip sequences for a chip rate of 2 Mchip/s.

C. Comparison betwwen KNX-RF and ZigBee

Wireless standards can be distinguished by the way they use the spectrum available to them. Table 2 summarizes various aspects of the radio standards considered, relating to the properties of the two lower layers of the ISO/OSI model.

TABLE II: PHY LAYERS OF KNX-RF AND ZIGBEE 2.4 GHZ

Parameter	ZigBee (world)	KNX-RF Multi (Fast)	KNX-RF Multi (Slow)
Frequency	2.4 GHz	868 MHz	868 MHz
Max. TX Power	20 mW EIRP	25 mW ERP	25 mWERP
Data rate	250 kb/s	16.38 kb/s	8.19 kb/s
Spectrum usage	DSSS $4 \rightarrow 32$	Single Carrier	Single Carrier
Channels	16	3	2
Modulation	O-QPSK	2-FSK	2-FSK
BW_{eff}	2 MHz	164 kHz	76 kHz
ARQ	Optional (def. 3 retries)	Optional (Fast ACK)	Optional (Fast ACK)
Channel Access	CSMA/CA	LBT for channel selection	LBT for channel selection
Duty Cycle	n/a	1%, 0.1%	10%, 1%

In addition to the technical characteristics of the physical and medium access layers, standards can also be distinguished by various design aspects in the higher layers (Table III). Those aspects can affect both technical considerations like range or battery lifetime, and non-technical ones like ease of use and customizability.

In terms of configuration, as opposed to ZigBee whose devices are only configured with a push-button solution, KNX-RF offers a double way configuration: push-button and the Engineering Tool Software (ETS) which is a manufacturer independent configuration programming tool for the design and configuration of intelligent home and building based on KNX certified systems. The integrated monitoring in ETS gives the installer the advantage of checking his installation.

TABLE III: KNX-RF AND ZIGBEE DESIGN CHARACTERISTICS

Category	Topology	Multi hop	Sleep mode
KNX-RF Multi	Direct connection	Pre-configured repeaters	Sensors, Short sleep cycles for fast actuators with short preamble (15 ms), Long sleep cycles for slow actuators with long preamble (500 ms)
ZigBee	PAN coordinator required	Dynamic routing (tree and source)	Beacon-less: sensors or slow actuators with data polling; Beacon-enabled: sensors, actuators

The radio range performances of KNX-RF and ZigBee 2.4 GHz were studied through simulation and experimental tests. This study is important because the smart meters can be installed in different locations within the house: garage or cellar, isolated with limited propagation conditions (concrete, remote, etc.), in the heart of the house or at the apartment entrance (best case) in urban areas, or outdoors (suburban or rural area). In this case, the radio range must be optimized.

A collaboration between Hager Controls and the technical university of Dortmund allowed modeling the radio ranges of the two considered protocols (1).

$$\text{Sensitivity}(\text{dBm})\text{-EIRP}(\text{dBm}) =$$
$$G_{Ar}\Big|_{\text{dBi}} - \eta(f)10\log\left(\frac{d}{d_0}\right)\Big|_{\text{dB}} - 20\log\left(\frac{4\pi f d_0}{d_0}\right)\Big|_{\text{dB}} \tag{1}$$
$$-\sum_{i=0}^{n_{walls}} L_{wall}(i,f)\Big|_{\text{dB}} - \sum_{j=0}^{n_{floors}} L_{floor}(j,f)\Big|_{\text{dB}}$$

where η is the path loss dependent upon the frequency, d is the distance between devices, d_0 is the reference distance up to which quadratic power decay is assumed. The remaining parts describe the attenuation of the intersecting walls and floors: $L_{wall}(i,f)$is the i^{th} wall attenuation at the current transmission frequency and $L_{floor}(j,f)$ is the attenuation of the j^{th} floor.

The Packet Loss Rates (*PLR*) versus the distance range were simulated based on equations (1) and (2) for KNX-RF physical layer in different indoor conditions (Table IV). An output power of 10 dBm was used.

$$PLR = \overline{\left(1-\left(1-\left(\frac{1}{2}e^{-\frac{B}{2f_b}SNR}\right)\right)^{PL}\right)^{3}} \tag{2}$$

TABLE IV: CONDITIONS FOR THE KNX SIMULATIONS

$F+I$	16 dB	f_T	16.384 kbit/s
P_S	10 dBm	f	868 MHz
PL	193 bit	$L_{wall}(f)$	868 MHz: 3 dB
		$L_{floors}(f)$	868 MHz: 12 dB

Fig. 4 presents the *PLR* versus the distance of KNX Multi "Fast". Dashed lines represent the KNX-RF standard which works without retransmission (Fast-Ack). Solid lines refer to KNX-RF Multi with retries on each frequency. Same simulations were done with KNX Multi "Slow" which gave greater results for the distance with a corresponding *PLR* difference of 5.10^{-4}, which is normal because the data rate is half of the one of KNX Multi Fast.

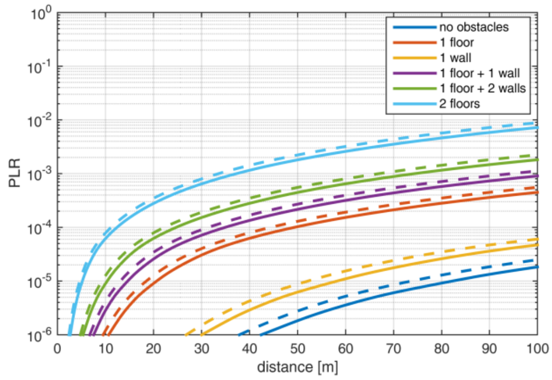

Fig. 4. PLR versus distance of KNX-RF multi fast.

The same work was performed with ZigBee 2.4 GHz and by using the equations (1) and (3) in different indoor conditions (Table V).

$$PLR = \overline{\left(1-\left(1-\left(\frac{8}{15}\cdot\frac{1}{16}\cdot\sum_{k=2}^{16} -1^{k}\binom{16}{k}e^{20\cdot SNR\cdot\left(\frac{1}{k}-1\right)}\right)\right)^{PL}\right)^{4}} \tag{3}$$

TABLE V: CONDITIONS FOR THE ZIGBEE SIMULATIONS

$F+I$	13.6 dB	f_T	250 kbit/s
P_S	7 dBm	f	2.4 GHz
PL	256 bit	$L_{wall}(f)$	2.4 GHz: 6 dB
		$L_{floors}(f)$	2.4 GHz: 15 dB

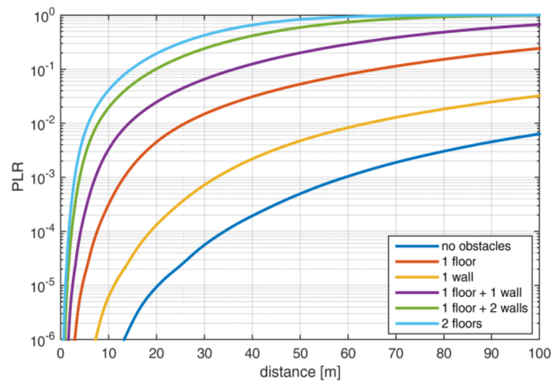

Fig. 5. PLR versus distance of ZigBee at 2.4 GHz.

Fig. 4 and Fig. 5 show that a typical range in a house is from 40 up to 70 m for KNX-RF Multi and 10 to 35 m for ZigBee. The Sub-GHz frequency is more convenient for smart meters located in the street or in difficult propagation conditions. ZigBee is can be easily used in apartments.

Real test of read ranges with both protocols were performed in a typical 2-story house including a basement that was selected as the test facility. It has a surface of approximately 27 meter-by-17 meter on each floor, except the basement which has a 10 meter-by-4 meter surface. The house walls are of concrete and brick structure. The real estate area including the gardens is 50 m-long and 17 m-wide.

The references of KNX-RF devices used for the test are: TRC270F, WKT306R, TRB201 [14].

The references of the ZigBee devices used for the test with are: the wiser smart plug EER40000 and box ER21000 [15]; the smart plus 0 883 24 and the remote control 5-738-70 [16].

Fig. 6. KNX-RF read rangeexperimental results.

Fig. 7. ZigBee read range experimental results.

Experimental tests (Fig. 6) show that the distance reached between the transmitter and KNX-RF receivers are better than that reach with ZigBee receivers, which agree with simulation results. The mean range of the KNX products is about 50 m. The mean range (Fig. 7) for the ZigBee product is about 20-30meters.Note that there is a difference between the theoretical simulations and the real performances of products: there is an inaccuracy due to the type of the used RF chip, which do not deliver the same radio output power and sensitivity, also due to the quality of the RF design on the PCB hardware, whether the product is powered by 230 V or batteries, etc.

TABLE VI: ENERGY CONSUMPTION OF DIFFERENT DEVICE TYPES FOR EACH TECHNOLOGY UNDER A 3V VOLTAGE

Type of device	ZigBee (world)	KNX-RF Multi
Sensor	1.5 µA	4.8 µA for Fast channels 47 µA for Slow channels
Fast Actuator	24 mA	Between 1.3 mA and 3 mA (Rx)
Slow actuator	885 µA	39 µA (550 ms latency)

The consumption of the protocol is also calculated. For KNX-RF analysis, a Semtech SX1211 transceiver IC is evaluated. It operates in the 3V range, with a transmit current of 25 mA, a receive current of 3 mA and a sleep current of 2 µA [17]. Regarding ZigBee, an example chipset of a TI CC2538 SoC is used. It can transmit at up to 7 dBm with a power consumption of 34 mA while transmitting, 24 mA while receiving, 7 mA while idle and 1.3 µA while sleeping [18]. Table VI gives the average current consumption under a bias voltage of 3V, for different types of products.

The results given in Table VI depend on the performances of the RF chip and the balance between the transmitter and the receiver current consumption. It also shows that it is possible to design a full KNX Multi Slow system with battery-powered products and a latency of about 500 ms. This is not the case of the protocol ZigBee which always needs a main-powered coordinator. In the case of the Smart meter, it is not useful, depending on what the user wants to do with its management box (extension of the network or not). The IPV6 possibility included in 6LoWPAN through the common layer 802.15.4 with ZigBee is an interesting function for the future deployment of the Internet of Things.

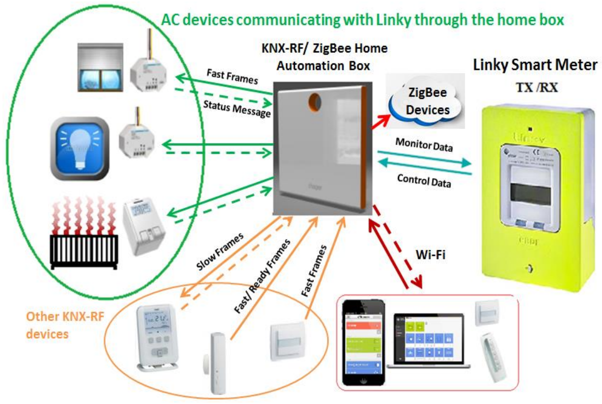

Fig. 8. Linky interaction with a multi-protocol home automation gateway.

IV. DESCRIPTION OF SCENARIO WITH KNX-RF PROTOCOL

As mentioned previously, the energy manager system can be a wireless home automation box that is a Multi-profile Multi-protocol device. It is composed of a KNX-RF Multi module that can manage all KNX-RF available communication profiles (Ready, Multi Fast, Multi Slow) and can be further extended to other home automation protocols (ZigBee, EnOcean...) and Wi-Fi. Besides, this Multi-protocol home box can interact with Linky smart meter to monitor and control electrical household appliances via KNX-RF actuators (Fig. 8).

To investigate the radio performance of a home automation installation that includes a Linky Smart Meter, a worst case scenario was considered: a house including 58 home automation devices (52 KNX-RF devices and 6 Linky E-meter devices). The total number of Fast and Slow frames and their respective total occupation time over a ½ day are reported in Table VII.

The calculation of “Fast” frame media occupation for this scenario gives about 2 minutes occupation time and the probability of collision gives a frame error rate of 0.12%. This is far below the maximum allowed bit error rate 10^{-4}that is indicated in the KNX-RF standard, which corresponds to an FER_{max} of 2% for Fast frames.

In fact, the box allows adding other automation protocols like the energy harvesting protocol Enocean to extend the network and provide additional comfort in the installation. However, it is not possible to use this technology in the Linky meter because it is based on the very low consumption of its transmitter which relies on energy harvesting to replace the need for conventional power sources (wires or batteries). Yet, Linky is a main-powered transmitter. As for the receiver, it should always be main-powered except in case of heating valve (See beck effect and solar cells).

TABLE VII: PROBABILITIES OF LOSING FAST FRAMES DUE TO CROSS INTERFERENCE INSIDE THE HOME AUTOMATION BOX

		Number of devices	Number of actions per 12 Hours	Fast duration (ms)	Slow duration (ms)	Number of Fast frames	Number of Slow frames	Fast total media occupation (ms)
Open-window sensors		8	4	42	550	32	32	1344
Heating water valves		10	6	42	550	60	60	2520
Heating 230-V actuators		5	6	42		30		1260
Shutter commands		8	4	42		32		1344
Light commands		8	10	42		80		3360
Indoor thermostats		8	48	42		384		16128
Outdoor thermostat		1	48	42		48		2016
Light sensors		4	144	42		576		24192
E-meters (Linky)		6	144	46		864		39744
Status messages	Light	8	10	42		80		3360
	Shutter	8	4	42		32		1344
	Valve	15	12	42		180		7560

	Fast frames
Rate of occupied time over 12 Hours	0,24%
Rate of Lost Frames over 12 Hours	0,12%

In case the box has to incorporate the EnOcean technology, EnOcean occupation of the KNX-RF radio media when cross interference occurs is estimated to 0.2% for a scenario where 10 EnOcean devices are each transmitting 10 packets per day, with up to 3 frame repetitions. It can therefore be concluded that EnOcean interference with KNX-RF would not impact the global system robustness since the resulting FER is not significant.

TABLE VIII: ENERGY CONSUMPTION OF DIFFERENT DEVICE TYPES FOR EACH TECHNOLOGY UNDER A 3V VOLTAGE.

Type of device	Ref.	Nbof pro-ducts	Source	Lifetime of batteries	AC-DC consumption (mW) Current(mA)
Open-window sensors	KNX [14]	8	2 AA	>7 years	-
Heating water valves EER53000	ZigBee [15]	10	2 AA	~2 years	-
Heating 230-V actuators	KNX [14]	3	230 V	-	42 mW 0.55 mA
Heating 230-V actuators	ZigBee [15]	2	230 V	-	1000mW 10.5 mA
Shutter commands WKT304	KNX [14]	8	CR 2430	>7 years	-
Smart plug TRC270F	KNX [14]	2	230 V	-	42 mW 0.55 mA
Smart plug EER40000	ZigBee [15]	2	230 V	-	680 mW 8.9 mA
Smart plug 0 883 24	ZigBee [16]	1	230 V	-	1100 mW 12.7 mA
Remote Control 5 738 70	ZigBee [16]	1	CR 2032	N.A	-
Light commands WKT304	KNX [14]	8	2 AA	>7 years	-
Indoor thermostats EER51000	ZigBee [15]	2	3 AAA	~1year	-
Light Sensors	KNX [14]	4	2 AA	>7 years	-
Linky product	ERDF	1	230 V	-	130 mW max
Overall Con-sumption		8 AA 3AAA 1CR2430 1CR2032			4800 mW
		KNX-RF devices overall consumption			210 mW
		ZigBee devices overall consumption			4460 mW
		Linky devices overall consumption			130 mW

The module could be placed inside the box, at only few centimeters away from other radio modules operating on the same frequency band. Thus, interference between radio protocols may occur. To investigate this issue, a software tool was developed under Matlab/Simulink that enables to determine the desensitization of devices [19]. The simulation results showed that the radio range of KNX-RF Multi Fast (F_3 channel) when operating beside EnOcean reduces by20 meters in a line of sight indoor environment. However, as EnOcean frames are ultra-short (~1ms) and follow a random time repetition mechanism, the probability of collision tends to 0 considering that KNX-RF Fast frames last 42 ms and can be repeated no more than 3 times.

Besides, the simulator showed that placing a 2.4 GHz ZigBee radio module beside the KNX-RF (868 MHz) module does not result in any interference since the two protocols operate in separate frequency bands.

To understand the overall standby power consumption of a mixt system, an example with several ZigBee and KNX devices is chosen and presented in Table VIII. The 230V AC-DC power and current consumptions were measured with a WT210 Yokogawa digital power meter [20].

V. Conclusion

This paper describes the overall operation of smart grid intelligent network management and the benefits of using the smart Linky meter which is based on two protocols: KNX-RF 868 MHz and ZigBee 2.4 GHz. Comparisons between these two protocols showed that radio ranges over the 868 MHz frequency band used for KNX-RF are more convenient for the smart meter installation as the range is approximately two times higher than for the 2.4 GHz band.

In this work a worst-case scenario was studied. The consumption of a home automation system including a number of smart Linky meters was established along with the occupation of the radio media. It helps in figuring out whether the scenario is relevant enough and whether it will enable fast moving towards the world of the Internet of Things. Besides, further work should be made on devices that consume significant amounts of power during their standby mode if their energy efficiency is not optimized.

To make this global "Smart Grid -Smart Home" system operational, interoperability between protocols is required from the smart home automation perspective and from the configuration perspective between the meter and the central energy manager which interacts with downstream devices. Furthermore, a connection to internet is relevant to better perceive all these benefits and provide additional system optimization.

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