IQRF Street Lighting - A Case Study

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Abstract— **In this paper, we present main features of IQRF, new communication framework specifically developed for wireless sensor mesh networks and its applications such as intelligent lighting systems. Basic components and functions of IQRF are described. The case study evaluates the existing work on wireless sensor mesh networks for a street lighting scenario and shows number of key mesh network parameters having influence on overall performance of a deployed system. The key parameters were also practically and successfully verified in a test experiment.**

Keywords- frameworks; wireless mesh; intelligent lighting systems; sensors network

I. INTRODUCTION

Street lighting control systems are centralized systems which control and monitor the status of street lamps installed along a road. Lights are switched on/off by the system control commands, or, if equipped by light sensitive photocell, then lights are being automatically turned on at dusk and off at dawn. Its local status information is also monitored by control system and reported back to municipal control centre via a communication channel. Among many information being monitored, there might be light status information (on/off), energy saving status (dimming percentage), lifetime period of key lamp elements (maintenance purposes) and safety related information (failures at pedestrian crossing), etc.

To convey control commands and status information between street lighting control system and remote light control terminal installed at each light pole, various types of communication medium and protocols are being used. Regarding the communication media, Power Line Communication PLC or Radio Frequency RF is used commonly [2].

The rationale for these communication media being widely used is their easy installation and low maintenance procedures. In both cases, there is no need to install additional wiring and therefore they are more economically viable than other type of communication media.

Comparing PLC lines with RF channels, both have their own pros and cons. PLC type of communication suffers from an interference from nearby electrical systems, signal attenuation by transformers and DC-DC converters and short circuit problem. On the other hand, RF communication channel parameters tend to deteriorate with worsen weather conditions such as heavy rain or snowfall. Longer communication ranges along with support for dynamic WSMN are essential key factors to maintain certain degree of redundancy in RF communication and thus deliver high reliability of the control lighting system.

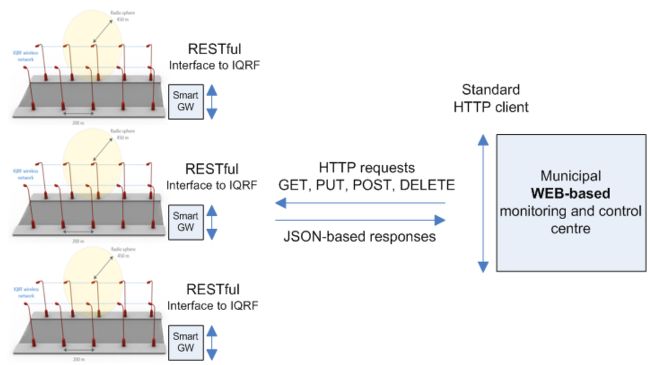

Figure 1. Towards a service-oriented IQRF architecture – street lighting scenario

Maintenance is another important factor. With automatic lights monitoring in place, the system is able to predict lamps failures before they actual happen. This enables to develop more efficient maintenance scheduling plans. In order to further reduce cost and number of maintenance persons, lighting control systems should have high stability and provide required information when needed. For these reasons, reliable communication technique is essential. In this paper, the technology which lays solid foundation for intelligent lighting systems is being further discussed.

The focus of this paper is more on RF communication for our ability to show already gained experience with available RF technology relevant to the selected scenario.

The paper is outlined as follows: First, we present related work in the area of wireless sensors frameworks. We describe new features of IQRF framework in Section 3. Simple implementation of on/off control with status monitoring, a partial task in many street lighting systems, is presented and discussed in Section 4. We conclude with remarks and plans for future work.

II. RELATED WORK

Many solutions supporting low power communication and advanced network topologies are available on the market

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nowadays. Many of them are based on Low-Rate Wireless Personal Area Networks (LR-WPAN) 802.15.4 [3], Zigbee [4], and 6LoWPAN [5] standards. Following are described platforms based on the mentioned standards.

Arduino [6] is an open-source electronics prototyping platform based on flexible, easy-to-use hardware and software. The platform was designed for artists, designers, hobbyists, and anyone interested in creating interactive objects or environments.

Jennic [7] is a commercial platform which offers a complete set of wireless microcontrollers, modules, design and development tools. This is complemented by a suite of software that includes network protocol stacks, profiles and APIs as well as application reference examples.

Epic [8] is a open mote platform for application-driven design. A key goal of the Epic project is to develop a composable hardware architecture for WSMN modules that specifically supports prototyping, measurement, and reuse. Epic facilitates prototyping through componentized hardware with flexible interconnections between both the components themselves and third-party hardware.

SuRF [9] is type of module which is based on principles of open-source model and brings the state-of-the-art IPv6 implementation into possibly any electronic device. It is also among first modules which takes advantage of single chip solution (MCU and RF combined together) working in sub GHz band.

IQRF [10] communication framework introduced in this paper takes similar approach as the platforms mentioned above, however IQRF explores more the space of sub GHz bands (868 MHz and 915 MHz) and is equipped by routing mechanism supporting unique 240 routing hops. Further, it brings with itself the merit of simplicity to be applied and as a result of it very fast prototyping and final wireless design. It is a purpose of this case study to also pinpoint and analyze the key parameters of IQRF communication framework and show their influence on the selected scenario.

III. IQRF FRAMEWORK

IQRF is the communication framework. The name IQRF stands for an Intelligent Radio Frequency. IQRF is the framework integrating variety of components for building LR-WPAN in an easy way, simplifying and shortening design phase of a wireless communication system. Basic system components and functions will be described in next sections.

A. Transceiver modules

A transceiver module (TR) is the basic communication component of the IQRF framework. The TR is a tiny intelligent electronic board with complete circuitry needed for realization of wireless RF connectivity. A micro-controller with a built-in operating system having debug functionality enabled together with an integrated LDO regulator and temperature sensor dramatically reduce a time of an application development. The low power consumption in receive mode (XLP 35uA) predetermines these modules to be used in battery powered applications. Complete set of modules parameters are shown in Figure 2.

A highly integrated design in the SIM card format (25 x 14.9 mm) requires no external RF components and provides efficient way for application firmware development. The modules can be easily integrated into any electronic device via inexpensive and commonly used SIM card connector. An electronic device printed circuit board (PCB) would be populated by the SIM connector and optionally equipped with the TR module. This approach enables manufacturers utilizing the TR modules to sell both either non-communicating versions of the electronic products or optionally equip them with wireless connectivity. The versions with an integrated antenna perfectly support this option.

Solderable versions of the TR modules (TR-53B) fully compatible with their SIM versions would address the applications facing higher mechanical stress. A compatibility with their SIM versions enables easy application development and final seamless migration to solderable versions.

Type			TR-52B	TR-53B	TR-55D
Physical interface			SIM	SIM / SMT	SIM / SMT
Number of pins			8	9	9
I/O			6	7	7
MCU PIC			16F886	16F886	16LF1938
Flash memory			8 K x 14 b	8 K x 14 b	16 K x 14 b
RAM			368 B	368 B	1024 B
EEPROM			256 B	256 B	256 B
RF power			3.5 mW	3.5 mW	3.5 mW
RF range			700 m	700 m	700 m
RF bit rate			86.2 kb/s	86.2 kb/s	115 kb/s
Supply current	sleep		2 µA	2 µA	1 µA
	run		17 µA –1 mA	17 µA –1 mA	17 µA – 6 mA
	receiving	LP	400 µA	400 µA	400 µA
		XLP	35 µA	35 µA	35 µA
	transmitting		14–24 mA	14–24 mA	14–24 mA
Temperature sensor			yes	–	–
A/D inputs			2	3	3

Figure 2. Key parameters of the TR modules

The TR modules are available in several families, each utilizing different peripherals and functions, to fit different user's requirements. Different frequencies in the license-free ISM bands would be utilized: 868 MHz in EU, 915 MHz in US.

Overall parameters for every TR module, specific datasheets and cross-table parameters overview, are shown in Figure 2.

B. IQRF Operating System

Every TR module is equipped with the operating system (IQRF OS) implementing basic functionality. IQRF OS is buffer oriented and its block scheme is shown in Figure 3.

IQRF OS controls a radio frequency integrated circuit (RFIC) and supports all communication processes: transmitting (TX), receiving (RX), network bonding, routing, etc.

Data processing (encoding, encryption, check-sums, adding headers, etc.) is made automatically by IQRF OS during communication processes, parameters affecting such

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processing would be setup before calling communication function. Setting, e.g., variable DLEN (data length in the packet) to be equal to 16 and a consequent call of a RF transmit function would result that the first 16B from bufferRF would be encapsulated to the packet and transmitted.

All RF parameters are software tunable and their setting depends solely on the application requirements. Options of having: 868MHz/916MHz bands; 62/189 channels; 1,2 kb/s up to 86,2 kb/s rates and transmit power up to 3,5 mW. Receiver sensitivity is also adjustable and allows to filter incoming signal according to application need for particular environment. The signal strength can be also periodically checked even while TR being in a receive mode and thus enabling to use clever techniques to increase communication reliability and at the same time to lower power consumption.

In current version of IQRF OS [11], set of addressing and routing options was extended yet simplified for an end user. There might be up to 65000 active devices in a single IQMESH network [13] with routing capability up to 240 hops (700m/hop). The addressing and routing schemes are separated from each other. The addressing is fully under the control of an application developer and on the other hand routing is fully transparent (no need to select routing path) and operating in real-time.

Another new feature of IQRF OS is a discovery mechanism. The discovery allows a network to be logically reconfigured in optimal way for a particular routing option. This further enables to deploy devices without consideration of placing devices in certain way from network coordinator. The discovery mechanism itself is also transparent and very fast. IQRF OS implements support for general mesh network (full MESH) but also supports different set of routing algorithms according to specified topology (Reduced MESH, Optimized MESH, Tree, etc.).

A flexible power management is crucial factor for battery operated devices. There are two important elements which influence power consumption of the TR module. Firstly, it is power consumption in sleep mode and secondly in receive mode. Well designed TR has in sleep mode power consumption of a few uA which yields battery lifetime around 10 years. In most WSN applications, there is a big disproportion in time the transceiver is RX compare to TX during an application life cycle. Thus power consumption in RX mode contributes the most to overall power consumption of the TR. IQRF OS allows the application developer to select among 3 options for receiving modes: standard (STD), low power (LP) and extra low power (XLP). Each of the receiving mode has a corresponding transmitting mode to match up to. Mode selection is driven by application requirements and depends on many factors such as: network throughput, response, length of the packets , use of battery, etc. TR modules consume 2 uA in sleep mode and unique 35 uA in XLP mode. The sleep mode is implemented by turning off all the TR components and then enabling interrupt on change on the MCU input.

There is no special buffer strategy implemented in IQRF OS. There are dedicated buffers for each communication channel (RF, SPI, EEPROM) as shown in Figure 3. It is up to an application to handle correctly these buffers.

In a nutshell, IQRF OS substantially simplifies the design phase and allows a programmer to fully focus on application logic. Besides its basic functionality, IQRF OS provides also a mechanism for application upload when an application is compiled. The programmer will set the TR module into the programming mode and via SPI interface the application code is uploaded to the module as shown in Figure 5. Another method for application upload is via RF and called ICWP (In-Circuit Wireless Programming). ICWP allows multiple TR modules to be programmed simultaneously.

An additional layer on top of IQRF OS so-called plug-ins [13]. An idea of the plug-ins concept is to tailor IQRF OS functionality according to user's requirements instead of exposing complete set of functions implemented by IQRF OS. A user would not be able to use both UART or I2C and SPI at the same time since these microcontroller (MCU) pins are multiplexed. Therefore, the only one communication plug-in will be used at a time to avoid wasting of the program memory by having all protocols included in the OS built.

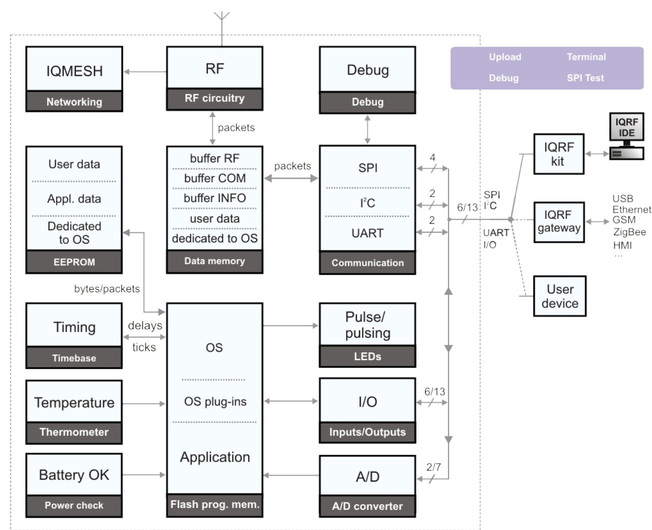

Figure 3. IQRF OS structure

A complete set of functions can be found in [1].

C. Gateways

An external access to the IQRF WSMN is enabled through the gateways. Generic and static types of gateways are distinguished in the IQRF framework [12].

The static gateways provide external connectivity to the IQRF WSMN based on defined fixed protocols. The gateway consists of the TR module providing wireless connectivity together with a dedicated MCU implementing a specific protocol. An Ethernet gateway GW-ETH-01 has Ethernet interface supporting TCP and UDP communication. Based on the gateway's configuration the packets coming from IQRF WSMN can be stored in a round buffer of the gateway and later picked up by an external server application or directly sent via Ethernet. In opposite direction, data is encapsulated to the IQRF packets and sent directly to the IQRF WSMN. An application layer and function of TR module might be fully customized.

The generic gateways would be customized completely. Both the application layer of the TR module and gateway's MCU would be fully programmed. Based on this mechanism, the generic gateways can provide custom specific functions. Advantages would be seen in the GW-QVGE-01, a human interface device implementation. The objects such as menus, buttons or texts and their specific events will be usually different for every customer's application.

D. *Development tools*

As it was mentioned, the TR modules have built-in OS therefore the only application layer needs to be developed. The simpler applications and examples for the TR modules can be directly downloaded from the website [1], while specific and customized functionality should be developed and programmed. A typical development process based on this concept is shown at figure Figure 5.

To effectively develop, program and debug applications for the TR modules, wide range of hardware and software development tools has been introduced - programmers, development kits and development sets.

The programmers such as CK-USB-04 [1] used in the case study are dedicated to upload compiled application into the modules and also to provide debugging interface during the application development. The development kits such as DK-EVAL-04 [1] used in the case study are modular ready-to-use pieces of HW which would be used for debugging and communication or range testing.

IQRF integrated development environment (IDE) should be mentioned as a basic tool providing complete functionality for the application development - system debug, SPI debug Terminal and Programming/Upload.

E. *Function Specific Components*

Next IQRF components with specific function were added to the IQRF portfolio to help with maintenance task on a site.

The solution is being prepared and is going to be based on graphical IQVCP type of device [14] which is able to join street lighting IQRF network and send diagnostic requests to each lamp. For the field operations, an IQVCP device is able to run from the battery. Shown in Figure 4.

Figure 4. IQVCP scanner

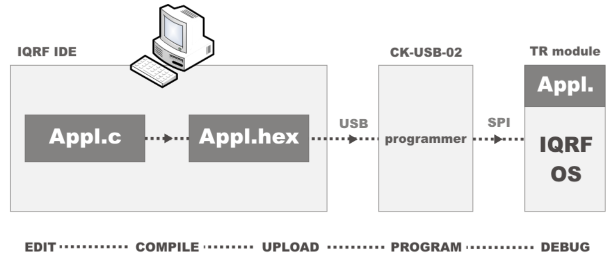

Figure 5. The development process and tools

IV. THE CASE STUDY

Radio waves are affected by the same phenomena like light waves: reflections, absorptions, diffraction, etc. These phenomena strongly influence signal propagation. Radio waves on the frequencies used nowadays in LR-WPAN (sub GHz ISM bands and 2.4GHz band) are influenced by many factors such as the height above ground the modules are deployed, noisy environments usually found in cities (public transport systems, wireless door bells, etc.) and also outside weather conditions (fog, heavy rain, snow). The purpose of the case study is to prove on a simple example the convenient use of WSMN for street lighting systems and show key mesh network parameters along with techniques that influence overall system performance. For the demonstration purposes, the only standard IQRF components and development tools have been used.

A. *SIMULATION SCENARIO*

The simulations of the signal propagation were made for free space which is relevant to street lighting scenario. The TR-52BA-868 [1] modules at 868MHz band were availed and following conditions were applied for the test scenario: 1.60m over the ground, TX on maximum power 3.5 mW, antennas with gain 1.10dBi used both on TX and RX module and ground reflections 45%. The simulated graph is presented in Figure 6. Only near field is shown since far field linearly declines with distance. Based on the simulations and receiver sensitivity for 19.2 kb/s data rate, communication range was calculated as 470 m for a free space.

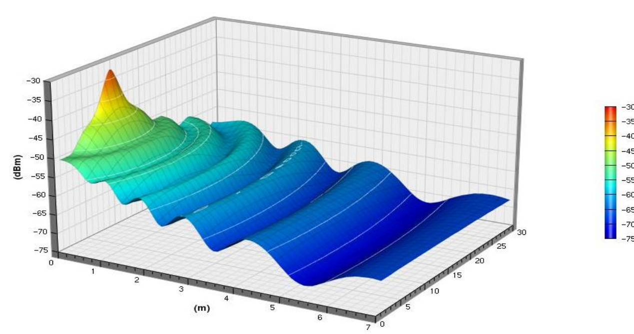

Figure 6. Near field simulation for 868 MHz free space with parameters relevant to the TR-52BA

B. EXPERIMENTS

A) Free space communication range measurement was realized with two new TR-52BA-868 modules each placed separately in the evaluation board DK-EVAL-03. An example E03-TR.c available from the website [1] was used, sending repeatedly packets with set data rate 19.2 kb/s and with maximum transmitting power 3.5 mW from one device to the other and back. The communication range was noted down when losing the packets were detected by a LED – 450 m communication range was measured.

TR-52BA-868 with its on-board mini PCB antenna has same radiating pattern as a usual whip antenna. The omni-directional radiating pattern is depicted on Figure 7 (right side).

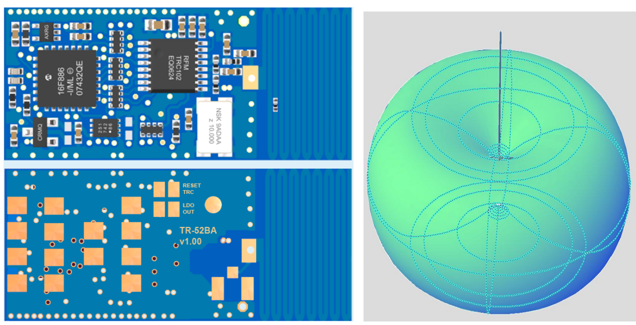

Figure 7. TR-52BA with its omni-directional antenna

B) A wireless network was built-up in the airport environment consisting of 20 modules TR-868-52BA placed to the evaluation boards DK-EVAL-04 and one CK-USB-04 establishing IQRF connection to PC running IQRF IDE.

An example E11-IQMESH-N.c available from the website [1] was tailored for the test scenario and used in the modules N1 - N20 simulating 20 street lamps. All modules were spread in two rows, having 10 of them in a row as depicted on Figure 8. For a network coordinator, E11-IQMESH-C.c was used and loaded into TR module placed in CK-USB-04.

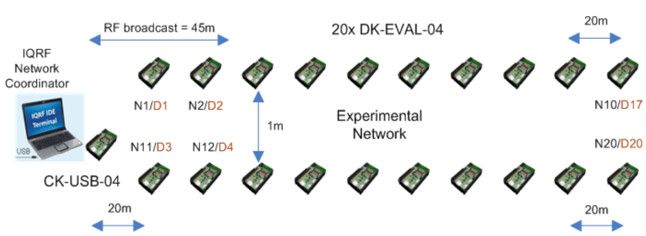

Figure 8. The experimental network

C) Installation phase: a real-life network was setup in the airport environment with a topology shown in Figure 8. The sensitivity of all receivers (all devices) was adjusted to 10^{th} of normal value. Doing that, the RF range was lowered to 45m, along with an assumption that all devices transmit at maximum power. To lower RF selectivity was decided based on a fact that it has much more fine-grained scale in comparison with output RF power. That resulted in better control over the network topology. Next is being discussed all necessary steps to setup and operate the network.

Firstly before actual deployment, all nodes simulating the lamps must be BONDED to the coordinator using standard bonding procedure which is well documented in an user guide to IQRF OS [1]. In our case, the coordinator is TR module placed in CK-USB-04. The bonding procedure assigns addresses to the bonded devices (N1-N20) and is fully under the user control. Bonding must be done within a direct RF range of the devices. It is a recommended practice to label each device with its assigned address.

Secondly, actual DEPLOYMENT of devices takes place. Since recommending to use routing algorithm Discovered Full Mesh (RTDEF = 2) there is no need to place the devices in specific order such as in Figure 8. They might be placed in random fashion. However, keep a map of the deployed devices (N1-N20) and its locations.

Thirdly, a DISCOVERY procedure is initiated by the network coordinator. Complete network is discovered and a virtual routing number VRN (D1-D20) is assigned to each device. D1-D20 are shown here only for an illustration and are not needed to be known for the routing purposes. To address a street lamp, the addresses N1-N20 are used and the routing itself is completely transparent for the user. It is a recommended practice to run the discovery procedure at lower TX power to avoid having same of the devices close to communication edge. It is also recommended to keep track of RSSI traces from the deployed devices at the coordinator and have them available for a comparison during the course of the year. If there is a change in physical network topology (replacement, adding new device, etc.) it is advised to initiate the discovery procedure again.

Finally, after the discovery procedure is finished it is recommended to POLL each device in the network in order to confirm that there is a RF link to every device. If succeed the network is ready to be used.

D) Routing: having full mesh routing supported brings the advantage of multiple redundant paths being available and thus lowering a likelihood of a packet not reaching its set destination. If the topology shown in Figure 8 is considered then the routing mechanism performs as follows. A command is transmitted from the network coordinator and in a first step is received by the devices N1, N2, N11 and N12. In order to avoid collisions to each device is assigned a time slot in which retransmits received command. Since the retransmission is also by broadcast, all devices in RF vicinity receive this retransmission. Next device to retransmit after the coordinator is N1 followed by N2 and so on. The command is being forwarded to its destination in described fashion. It is also important to mention that if a device receives same command twice it just simply discards the last one and keeps the original which to be retransmitted once there is a device's turn. A length of the time slot is set by the coordinator in a parameter RTDT1 (units of OS ticks) and might be variable depending on the length of the commands and expected responses. It is also worth mentioning that

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RTDT1 is inherited by all devices in the network once set by the coordinator.

Another important parameter is RTDEF which specifies type of routing mechanism. It is recommended to pick Discovered Full Mesh (RTDEF = 2) routing for the street lighting scenario. As described in the installation phase, once the network is discovered VRNs (D1-D20) are assigned. The sequence, in which the command is being forwarded in type of routing, is derived from VRNs (D1-D20) and not from bonded addresses (N1-N20). This allows the network to be further optimized in a sense of routing topology.

The last important parameter is RTDT0 specifying number of hops the command should be forwarded. It is possible to select RTDT0 according to number of bonded devices in the network. However, this would be only necessary in a case of having a chain mesh network. In other types of network, certain optimization techniques might be applied. More on the optimization might be found in a reference guide to IQRF OS [1]. There is always a trade-off being present between the level of redundancy and the command latency for the particular network topology.

E) For the field deployment as shown in Figure 8., the band 868 MHz and data rate 19,2 kb/s were configured. STD transmitting/receiving mode was used since there is no real emphasis on any power saving mechanism for the street lighting networks but rather maximum number of hops along with the packet latency is being considered. As described in previous paragraph, there are two routing parameters directly proportional to maximum configured hops and overall packet latency. In the field deployment, RTDT0 is equal to 20 and RTDT1 is equal to 1. With this setup in place, the coordinator is able to send short packets (up to 24B) and receive acknowledgment back from N20 within 0.5 s time frame. Further, the coordinator was configured to contact each node (N1-N20) in regular fashion. A pulling cycle was repeated every 5 min for 4 hours. During this run only HW related issue on N15 was encountered, which had no influence on correct performance of network primitives. The coordinator was able to collect all valid responses for the sent requests except for N15.

F) General recommendations for the street lighting networks are shown in Tab. 1. It is recommended to run a street lighting network in STD mode. Other modes such as LP and XLP are more suitable for battery operated devices. Others parameters are described in the table.

Recommended mesh network setup for a street lighting scenario	
Transmitter parameters	Receiver parameters
STD mode with default 3ms long preamble RF power = 7; 3.5 mW yields max range DLEN variable length of packet	STD mode with checkRF(5) RF sensitivity = 80%; lower the sensitivity to noise ToutRF = 1+ 1/24B in 10ms ticks
Routing parameters for a network coordinator	
RTDEF = 2; discovered full mesh network DISCOVERY_POWER = 6; discover network with lower tx power RTDT0 = number of hops to route a packet RTDT1 = time slot length 1+ 1/24B in 10ms ticks RX = address to send packet	

Table 1. IQRF street lighting recommendations

V. Future work

The future work within this project will be aiming at elaborating more on the idea of service-oriented architecture for IQRF and eventually for modern cities as shown in Figure 1. More specifically, the design of a smart gateway with RESTful interface [15] to IQRF will be further pursued along with practical verification of its usability in common cities environment.

VI. Conclusion

The main features and components of the IQRF communication framework were presented. Based on the standard IQRF components the IQRF-based WSMN was built to demonstrate basic operations in the street lighting systems and to experimentally verify the convenient use of WSMN in this application domain.

This network was used for the experiments presented in the case study. On this network, key mesh network parameters were shown and practically discussed. The recommendations for the key parameters were given to application designers in order to easy their task of developing WSMN network.

The experiments have proved WSMN topology to be also at best convenience for the street lighting applications.

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