IQRF Wireless Technology Utilizing IQMESH Protocol

Petra Seflova, Vladimir Sulc, Jiri Pos, and Rostislav Spinar

***Abstract*—This paper describes advantages, limitations and specifics of one particular low power wireless communication technology based on mesh network topologies: The IQRF platform utilizing the IQMESH protocol.**

***Keywords*—IQRF, IQMESH, networking, mesh, wireless.**

I. Introduction

COMPLEX RF technologies based on enclosed protocols are available for more demanding wireless applications like home automation. Many of them are based on the 802.15.4 standard defining Physical layer (PHY) and Media Access Control layer (MAC) for Low Rate Wireless Personal Area Networks (LR-WPAN). In sub GHz (433 MHz, 868 MHz, and 915 MHz) and 2.4 GHz bands there are a lot of proprietary or open systems providing mesh topology support.

ZigBee is based on the standard owned by the ZigBee Alliance [2]. Transmission rates are 20, 40 and 250 kb/s. It is intended for low power devices and low range (up to 75 m). Multihop ad-hoc routing enables also higher range without direct visibility. ZigBee is primarily used in industry and sensor networks.

Although ZigBee is relatively new, since 2004, after discovering that due to its high complexity and difficult usage, the implementation is not economic in smaller and some medium-sized applications, several lighter protocols were soon established, sometimes even by the original ZigBee Alliance members. One of such proprietary solutions is MiWi by Microchip Technology Inc., based on the ZigBee standard but simpler from the implementation point of view.

Other examples are a proprietary system with decentralized control by Z-Wave alliance [3] and 6LoWPAN applying IP (Internet Protocol) for low data rates. [4].

In addition to the standard features typical for the systems mentioned above, the IQRF [1] communication platform described in this paper offers several unique patent-protected features and is very easy to use which allows fast prototyping.

All results described here have been achieved within the IQRF R&D group except of the Street light application in chapter V. designed by a third party.

This paper is outlined as follows: the IQRF platform and its components are described in section II, mesh networking in section III and IQMESH in section IV. Finally two IQMESH implementations are introduced in section V.

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Authors are with the MICRORISC s.r.o, Jicin, Czech Republic (e-mail: seflova@microrisc.com).

II. IQRF

IQRF is an abbreviation for *intelligent* connectivity using *radio frequency* (RF). It is a complex communication platform with modular components for low speed, low power and easy to use wireless connectivity, either peer-to-peer or in complex networks. It was introduced in 2004 [7].

IQRF features:

- RF bands 868 MHz and 916 MHz (ISM)
- Based on transceiver modules with built-in operating system (OS) supporting IQMESH protocol
- Fully open functionality solely depends on user-specific application written in C language
- Packet-oriented communication, payload up to 128 B, variable encapsulation with respect to particular requirements
- Range up to several hundred of meters per hop, up to 240 hops per packet
- Up to 65 000 nodes in a network
- Low bit rate: 1.2 kb/s – 115 kb/s
- Extra low power consumption: 900 nA standby, 35 μA receiving
- No license fees

Application domains are telemetry, AMR (Automated Meter Reading), Smart metering, WSN (Wireless Sensor Networks), Smart grids, building automation, Smart house, HAN (Home Area Network), Smart cities including street lighting, industry and services. The platform is suitable for almost any electronic equipment where wireless communication is needed, e.g., remote control, monitoring, alarm, displaying of remotely acquired data or connection of more devices to a wireless network. The platform is described at [5]. Basic system components will be described in next paragraphs.

A. Transceiver modules

IQRF transceiver module (TR) is a basic communication component of the platform used not only in common end devices, but also in all IQRF gateways, routers etc.

It is an intelligent electronic board with complete circuitry needed for implementation of wireless RF connectivity with several peripherals and interfaces. It includes a microcontroller with built-in operating system (OS) supporting MESH networking, and optionally also serial EEPROM memory, voltage regulator (LDO), temperature sensor and built-in PCB antenna. Besides general I/Os, SPI running in OS background, I^2C and UART standard serials

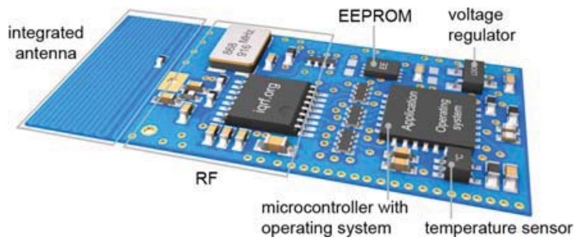

Fig. 1. Transceiver module

can be directly used. The tiny compact module with highly integrated design, typically in SIM card format 25 x 14.9 mm or less, requires no external components. Several TR types are available differing in performance, MCU type, memory size, peripherals, antenna options and dimensions.

Due to extra low power consumption, e.g., 35 µA while receiving, TRs are suitable even for devices with extreme requirements for battery life. All communication parameters are software selectable.

B. IQRF Operating system

Every TR module is equipped with an OS implementing more than 80 functions [1] for all standard tasks. It provides access to TR resources (memories, data buffers, peripherals, communication interfaces) and additional control and real-time features. Basic wired interface is SPI intended for upload, debug as well as for user communication. OS also includes RF buffer oriented packet communication (transmitting, receiving) and networking (bonding, routing, discovery etc.).

E.g.: To send 16 B of user data prepared in advance in bufferRF just data length DLEN=16 should be specified and the packet can easily be sent by the RFRXpacket() function. Encoding, encryption, encapsulation with checksums, headers etc. are made automatically by the OS. The OS can be extended or tailored for user needs by optional plug-ins.

IQRF OS substantially simplifies the design phase and allows a programmer to fully focus on application logic. IQRF IDE integrated development environment with debug feature is an efficient tool for user design and application. User programs can be uploaded into TRs via either wired or wireless connection as shown in Fig. 3.

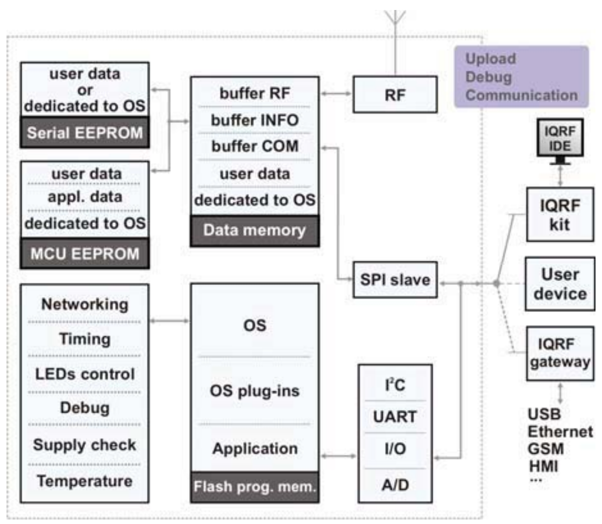

Fig. 2. Block diagram

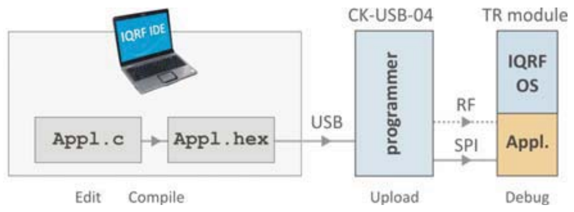

Fig. 3. The development process and tools

C. IQRF gateways

Simple communication standards (SPI, I^2C, UART etc.) can be realized directly by a standalone TR. Complex protocols (USB, Ethernet, GSM, CAN etc.) can be accessed via gateways (GW). A human operator can access an IQRF network also via VCP (visual control panels) [8] with keypads and displays/touch screens. Gateways offer also additional functionality: performance, extended memories, inputs/outputs, time/date, etc. The most demanded additional function is a datalogger to collect events and data.

For example, the Ethernet gateway GW-ETH-01 [9] enables connectivity between an IQRF wireless network and a local LAN and Internet. The GW has an internal web server allowing communication via HTTPS. Additionally, communication via the UDP transport layer is possible using the IQRF proprietary UDP protocol. One of the communication modes with internal TR module is a datalogger [9]. Data acquired by the TR is stored in a circular buffer in the GW and can be read, or user data can be sent from/to the TR via HTTPS. One of the real IQRF applications using IQRF GW-ETH-01 is the control system SIGMA for turning of pump vanes.

III. MESH

Mesh is a way to route data between a sender and an addressee using "hops" through other nodes in the network via alternative paths which ensures higher range and reliability.

A variety of routing algorithms claimed as suitable for low power wireless mesh networks can be found in the market. In fact, there is no universal mesh networking solution. Every application has different requirements therefore different algorithms should be used for specific applications.

IV. IQMESH

IQMESH (Intelligent Mesh) was defined in 2005 as a communication protocol for IQRF devices [1].

A. Basic principles

IQMESH utilizes a network coordinator that completely controls communication. Every TR can work as a coordinator or a common node. Up to 65 000 devices can work in a single network. Networks can be chained and every device can work in two independent networks, operating as a coordinator in one network and a node in another one, see Fig. 6. Every node can additionally route packets in the background, completely managed by OS and transparent from the user's point of view. Up to 240 hops per packet is supported.

Routing paths can be found automatically thanks to the discovery process creating virtual routing structure.

IQMESH supports various routing algorithms (Full mesh, Reduced mesh, Optimized mesh, Tree etc.) and 1 B or 2 B addressing. Routing can be static or dynamic, fully under the user's control or transparent. Dynamic timing with a selectable number of hops and duration of time slots allows achieving the highest throughput and minimal noise and power consumption. Routing efficiency and reliability is achieved through a flooding mechanism. Collisions are avoided through TDMA (Time Division Multiple Access).

Despite its high complexity, IQMESH can be ported on inexpensive microcontrollers with limited resources.

B. Addressing and routing

Every device in the network has a unique number (logical address) assigned during bonding. The DFM (Discovered Full Mesh) routing algorithm utilizes a virtual routing structure (VRS). It is created during the discovery process by the coordinator dedicating a unique VRN (Virtual Routing Number) to every routing device. Fig. 4a shows an example of a standard static network, where nodes are addressed by logical addresses N1 – N5. Virtual routing structure is added in figure Fig 4b for the DFM after discovery. Zones contain nodes with the same number of hops needed to access the coordinator.

Then, logical addresses serve to the user to specify the destination node while VRNs are used by the OS for routing. Flooding and other routing algorithms can benefit from systematic indexing of nodes by VRN reflecting the distance from the coordinator to the node. Routing based on logical address is also possible. It is suitable especially where nodes can be placed with respect to their logical addresses. TDMA enables directional, efficient and collision free transmissions. Individual routing algorithms can be combined each other. Packets are routed in dedicated time slots, see Fig. 5.

C. Discovery

During discovery, the coordinator seeks out nodes connected to the network to dedicate them unique VRNs, with respect to the distance from the coordinator. The coordinator starts to search its neighbors. All devices responding to its “Answer me” message will receive their VRNs. Based on received response, assuming that the link between coordinator and responding nodes should be symmetrical, routing paths to nodes and back to the coordinator are discovered. All nodes having a direct link to the coordinator belong to Zone 0, being directly accessible without routing.

Then the coordinator incrementally asks all nodes from Zone 0 to discover their 1-hop neighbors creating Zone 1 accessible from the coordinator by one routing hop etc., until there are no further nodes to discover. Then every discovered node has a unique VRN, see Fig. 4b. In typical applications such as smart buildings, telemetry systems and street lighting the discovery is made just once during the installation phase. To utilize the advantage of transparent routing, discovery should be repeated after any significant changes in topology (moving nodes, changed obstacles etc.).

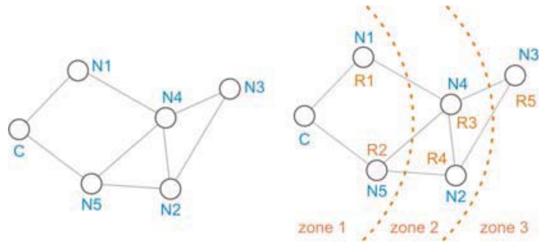

Fig. 4 (a) Logical addresses (N), (b) VRNs (R) after discovery

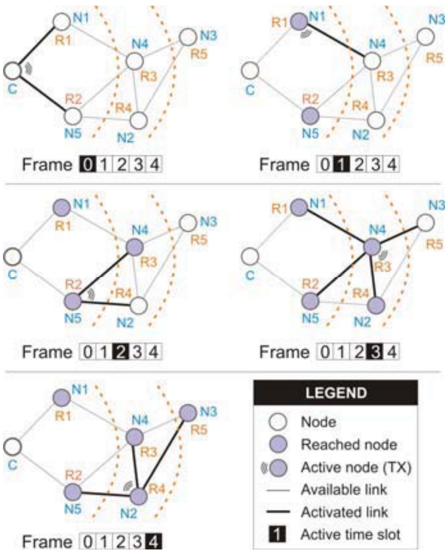

Fig. 5. Routing mechanism

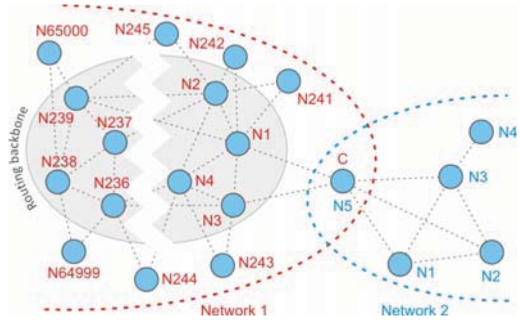

Fig. 6. IQRF abstracted network topology

D. Time synchronization

In contrast to many other techniques, e.g., [6], there is no need to share precise time information over the network. Routed packets keep track of the number of hops made. This number corresponds with the respective time slot based on VRN for every device. Reversed order to forward answers back to the coordinator is also arranged by the OS. This mechanism, together with adding information about the length of time slot, enables efficient re-synchronization of all devices based on packet reception. In addition, dynamic timing based on packet length is supported.

E. IQMESH limitations

IQRF platform is mainly used in LR-WPAN applications such as building automation and telemetry where many devices are parts of a fixed infrastructure, usually created during the installation, and provides permanent links to other devices. Possible nodes without permanent links, e.g. mobile devices, are accessible by flooding but should not be used as routers, see N241 and higher nodes in Fig. 6.

To increase efficiency, routing backbone is limited up to 239 devices, allowing very efficient one byte addressing, broadcast and group messages.

V. REAL APPLICATION

A. Street lighting

Centralized street lighting systems control and monitor the status of lamps along roads. Local status information is also monitored by control system and reported back to municipal centre. Light status information (on/off), energy saving status (dimming percentage), lifetime period of key lamp elements (maintenance purposes), safety related information (failures at pedestrian crossing), etc. can be controlled and monitored.

Fig. 7 shows one of such implementations realized in the suburb of Nitra, Slovakia, EU. A large part of the town ranging several kilometers is covered by 145 lamps using different channels to avoid spectrum concurrency, with output power 3.2 mW and small PCB antenna.

B. Control system SIGMA

SIGMA is another IQRF application. It allows controlling pump vanes from the panel at a pump as well as remotely from a supervision room. Additional requests are a possibility to control the pump, i.e. to change vane angle or the pump configuration remotely via Internet and supervision over events related to given pump.

SIGMA performs the following tasks: automatic reading from data buffer, data displaying, filtering and search, configuration of the pump, changing the angle of pump vanes, setup GW parameters etc.

The principle of automatic reading of the buffer:

GW-ETH-01 requests IQRF DNS server to detect its own IP address regularly (in 10 min increments in this case). The IQRF DNS server verifies the MAC address whether it is in allowed range (00.1F.D5.xx.xx.xx). Then it returns the IP address of a given device. Additionally, the server checks whether the device is registered in application SIGMA. If it is, the server requests GW-ETH-01 to send the data buffer and the GW returns the content. Application SIGMA

Fig. 7. Real implementation of street lighting application

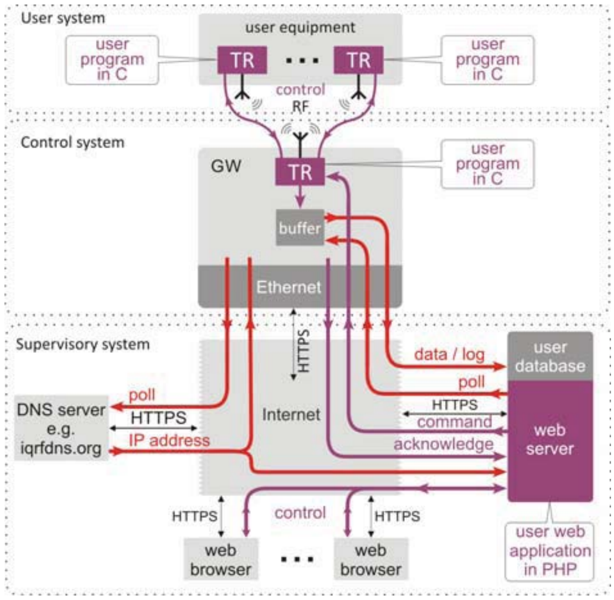

Fig. 8. Block diagram of complete system

recognizes new records (compared with the last reading) and stores them in the database. This principle is depicted on Fig. 8. Tests have been completed and, at present, the SIGMA application is being delivered to its final user for operation in practice in power stations.

VI. CONCLUSION

IQRF communication platform with IQMESH networking, its principles and routing algorithms, were presented. Like any other technology, IQMESH benefits from its advantages and is affected by its limitations. The flooding scheme is excellent for telemetry systems. On the other hand, many redundant links and consequent time delays can generate difficulties in real time applications and limited support for node to node communication technology require more programming work on application layer.

For further IQRF extension, enhanced concept of OS plug-ins and a higher communication level allowing even easier access to TR resources are under development.

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