Deployment of mesh network in an indoor scenario for application in IoT communications

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Abstract. The need for digital transformation in the industry and the related development of the Internet of Things (IoT) has led to the rapid development of various communication technologies and approaches for the implementation of flexible and intelligent communication networks. The main direction is wireless technologies, which make it possible to accelerate the wide range of new applications and services related to smart cities, industry, e-government and others. The possibilities are wide - use of different licensed or unlicensed frequency bands, channel bandwidths, modulation formats, power efficiency, reliability and security. Different network topologies could be applied for the access and collection of data from the sensor networks - star topology, mesh topology, tree topology, each of which has different advantages and disadvantages. This paper discusses the possibilities for deploying low-power mesh networks in an indoor scenario based on IQRF technology. Important communication parameters, approach advantages, and technological limitations will be highlighted. As an example, a study of network behaviour and efficiency in an indoor scenario will be considered.

1. Introduction

Wireless communication networks are widely used in various fields. Unlicensed bands, which for the European Union are 433 MHz and 868 MHz, are most often used for their application in Internet of Things (IoT) communications. These frequency bands are very often used for communication between sensors, actuators, equipment, controllers and remote controls, in home automation systems, in industrial automated systems, etc.

The IoT concept requires the implementation of a heterogeneous network environment in which the huge amount of data from multiple devices leads to some important issues: limited frequency spectrum resource, bandwidth efficiency, security requirements and more [1, 2]. Improving efficiency in IoT networks is most often achieved by aggregating traffic between end devices and applications. A huge number of IoT end devices share their data through a gateway and its management can be realized through various wireless technologies for data transmission over small and long range of distance. For this purpose, many communication protocols and standards have been developed (ZigBee, SigFox, LoRa, IQRF, etc.) [3, 4]. They use different approaches to design the network architecture, different transmission rates and maximum amount of data payload, different signal processing (modulation, error protection) and communication parameters (latency, transmitted power, transmission distance, power consumption, etc.) [5, 6, 7, 8].
One of the appropriate and promising technologies is the IQRF wireless communication platform. The IQRF platform was designed to address smaller segments of the wireless market – buildings automation, telemetry, utilization reporting for utilities, etc. The platform is distinguished by its specific methods for design of generic network communication platform, special signal coding scheme and direct peripheral addressing in a wireless network.

The IQRF technology/platform includes transceivers, gateways, development tools, communication protocols, and supporting services. The main parameters of IQRF are as follows [5]: sub-GHz ISM bands (433 MHz, 868 MHz, and 916 MHz); mesh or p2p network topology; reliable low-power communication (hundreds of nA in sleep mode and hundreds of μA in transmission mode); low data rate (about 19.2 kbps); low to medium coverage range (tens of meters in indoor scenario, hundreds of meters in outdoor environment); security level (the nodes are bound to the mesh network via password, AES-128 network encryption with self-distribution of the keys, AES-128 optional user encryption, CRC-16 message checksum, and block checksums); DPA (Device Peripheral Access) protocol for services and peripherals control. IQRF supports different MESH routing algorithms (full-mesh routing, reduced mesh routing, optimized mesh routing and others) and up to 240 devices in a single network with a maximum of 240 hops per packet (33 hops in 1 seconds with DPA method) [5].

Table 1 shows a comparison of IQRF with other short/medium and long communication range wireless technologies. The parameters presented in the comparison are derived from the technical documentation and various sources given in [8, 9, 10].

| Parameter                  | IQRF          | LoRa         | ZigBee       | SigFox       |
|---------------------------|---------------|--------------|--------------|--------------|
| Frequency band            | 433, 868, 916 (US) MHz | 433, 868, 780 (US), 915 (US) MHz | 2.4 GHz | 868, 902 MHz |
| Transmission rate         | 20 kbps       | 0.3 – 37.5 kbps | 250 kbps     | 0.1 kbps     |
| Maximum payload           | 64 byte       | 243 byte     | 128 byte     | 12 byte      |
| Range (in free space)     | 1 km          | 15 km        | 300 m        | 50 km        |
| Modulation format         | GFSK          | CSS          | BPSK, OQPSK  | DBPSK, GFSK  |
| Network topology          | mesh          | star         | star, mesh, tree | star         |
| Latency                   | 400 ms        | > 1000 ms    | 16 ms        | > 1000 ms    |
| Maximum power consumption | 15 μA         | 1 mA         | 30 mA        | 1 mA         |
| Maximum transmitted power level | 11 dBm       | 14 dBm      | 20 dBm       | 27 dBm       |
| Maximum number of nodes per gateway | 240 (DPA), 65.10^4 (OS) | 10^4 | 65.10^3 | 10^6 |
| Maximum battery power time | 5 – 10 years  | 5 – 10 years | 2 years      | 5 – 10 years |

The mesh topology of the network suggests to create local-based sensor nests with a higher density of sensors instead of operator-based connectivity to single sensors or groups of sensors over large-scale geographical areas. For this reason, it is of interest to study the scenario of indoor measurements. As a particular case in this paper, the study is based on an indoor environment, which is a single floor of a university building (figure 2).

2. Design of mesh network for IoT application with IQRF

The typical design of IQRF network with mesh topology is shown in figure 1. This topology includes IQRF transceiver modules, gateway, cloud service (network server) and user application.

The mesh network topology is implemented by wirelessly interconnected IQRF transceivers, which use a specialized routing algorithm to transmit data packets. The IQRF transceiver uses an 8-bit microcontroller that performs the operations provided in the operating system.
Two different approaches are applied for realization of a certain functionality. In the first approach, the existing hardware profile (HWP) in the three-layer IQRF architecture can be used through application software plug-ins. It allows access to all services and resources. This is an important advantage, as it does not require any special programming, but only control of data flows. The second approach uses a user application layer and predefined operating system functions. By using the C programming language, the desired functionality can be programmed.

In addition, there are two radio communication modes of operation. In the first mode, data packets are available to all devices in the range. Network features are not used here, i.e. this is a non-networking mode, which is suitable for peer-to-peer devices. In the second mode, one of the devices is assigned a coordinator role and manages the mesh network. A mesh network can contain up to 239 nodes, and data packets will be available only to the addressed nodes. The coordinator role can be dynamically assigned to each node in the network, and the other nodes are common nodes. This determines the maximum number of hops to be 240. Virtual routing of individual packets is applied, which allows to determine redundant paths in the network dynamically.

The IQRF gateway is used to provide an interface between the IQRF network and another type of network (Wi-Fi, Ethernet, 2/3/4G) to connect to the cloud server [11]. The gateways use a sensor node with the role of coordinator and it allows for data collection, accessing, and device controlling in the network.

The cloud server provides a service to end users and serves as an intermediary between them and the IQRF network. The gateway uploads the data received from the end devices directly to the server. Users can access the cloud server through a web and application user interface (API), which allows cloud monitoring.

3. Experimental setup for testing and measurements in an indoor scenario

Here will be considered an experimental setup for the implementation of IQRF network and scenarios for indoor measurement for a floor of the university building of Technical University of Gabrovo. In figure 2 is shown the floor architectural plan.

The following equipment was used for the experimental studies: two end devices (TX1 and TX2 – figure 2), a coordinator (C – figure 2), a Raspberry Pi based gateway (G – figure 2) and a cloud service. The network architecture for the considered indoor scenario is shown in figure 3.

The end devices (nodes) include a transceiver and a sensor module / relay module. The both transceivers are implemented with a DCTR-72DAT module operating at 868 MHz with 10 mW output power and –104 dBm sensitivity. The sensor module is connected to the first transceiver (TX1 – figure 2) and it is intended to measure temperature, light intensity (using a photoresistor) and voltage (using a potentiometer) (figure 4 (a)). The relay module is connected to the second transceiver (TX2 – figure 2) and it includes two bistable relays (figure 4 (b)). It enables to switch connected equipment on or off using two relays inside. Both sensor and relay modules are controlled by DPA commands.
implemented in custom DPA handlers delivered with the module. The handlers specify HWP identification (HWPIID) to individual modules which allows their identification.

Figure 2. The architectural plan and experimental setup of IQRF network in indoor scenario (TX – transceiver, C – coordinator, G - gateway).

Figure 3. The network architecture of the deployed IQRF mesh network for indoor scenario.

Figure 4. Block diagram of the two IQRF end devices: (a) with sensor module, (b) with relay module.

The coordinator is implemented with a DCTR-72DAT transceiver (i.e. with the standard IQRF transceiver but configured as a coordinator). It manages the configuration of the IQRF mesh network and the communication in it, as well as provides the virtual routing of the data. The communication between the end devices and the coordinator is through IQRF technology.

The IQRF gateway is based on a Raspberry Pi single-board computer via a DCTR-72DAT transceiver connected to it using a KON-RASP-01 adapter with a SPI (Serial Peripheral Interface) interface.
IQRF gateway daemon software is used to connect to the cloud service. Different platforms can be used as a cloud service, for example Microsoft Azure, IBM Watson IoT, IQRF Cloud, Google Cloud, AWS and others. The IQRF gateway transmit data to the cloud by using MQTT protocol (Message Queuing Telemetry Transport). As this paper examines the physical deployment of the mesh network, the cloud service is not covered in detail here.

4. Results

The performed measurements aim to analyse the operability and stability of the mesh network. All nodes in the network are distributed according to figure 2 and communicate through the coordinator with the gateway. To assess the quality of the radio connection, the value of the Received Signal Strength Indicator (RSSI) parameter is reported at regular intervals of 3 minutes within half an hour.

The reported RSSI values are presented in table 2. Based on these reported values and the RF sensitivity level of the DCTR-72DAT transceiver, figure 5 presents a comparative analysis of the change in the RSSI level within the measurement duration for the three nodes (both terminal devices and the coordinator).

| Timestamp, min | RSSI for TX1, dBm | RSSI for TX2, dBm | RSSI for C, dBm |
|---------------|-------------------|-------------------|-----------------|
| 0             | -85               | -83               | -66             |
| 3             | -86               | -83               | -64             |
| 6             | -85               | -82               | -64             |
| 9             | -85               | -80               | -65             |
| 12            | -87               | -78               | -65             |
| 15            | -86               | -78               | -65             |
| 18            | -88               | -80               | -66             |
| 21            | -86               | -82               | -64             |
| 24            | -84               | -82               | -64             |
| 27            | -84               | -83               | -65             |
| 30            | -86               | -83               | -65             |

Average level of RSSI: -85.63, -81.00, -64.91

Figure 5. Time variation of the RSCI level for a measurement period of 30 minutes.

The RF sensitivity level of the transceivers is considered as the minimum allowable in assessing the quality of the transmission, i.e. the measured levels must be greater than it. The results clearly show that all measured values are greater than this limit value. This shows that the IQRF network is a
convenient solution for the considered indoor scenario when deploying an IoT sensor network. It should be noted that the farthest node (TX1) is at a distance of about 45 m from the gateway, and communication with it takes place through multiple walls/obstacles (as well as communication with the node TX2). This further confirms the applicability, reliability and consistency of the implemented system.

As a future work it can be considered the application of IQRF technology in an outdoor environment with a much larger number of nodes, as well as to take into account the impact on network congestion and latency.

5. Conclusion

It is obvious that IQRF technology cannot be used for high data rate IoT applications. At the same time, the mesh topology, virtual routing and the specifics of data transmission ensure high network reliability. However, IQRF offers a longer range, higher sensitivity and better power-management (in exchange for lower throughput and higher latency). The presented results show good indoor and free-space signal spread, stable parameters for long-term measurements. However, there are some limitations such as the limited number of nodes in the network and average security without sufficient and clear key-management.

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