Wireless Home Automation Network Stability Testing

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***Abstract* - This paper describes stability testing of the new wireless communication platform for home automation. In the paper is description of two test-cases for wireless communication parameters evaluation to determine the limits of stability and low error rate. The paper also describes used statistical method and discusses testing results together with the main advantages of tested wireless communication platform. This new wireless communication platform was designed and developed especially for home automation and telemetry projects and test case results prove suitability of this wireless communication technology for home and office buildings environment.**

Keywords - Home Automation; IQRF, Wireless communication; Stability testing.

I. INTRODUCTION

With the advance of networking technology and wireless communications, the popularity and the applications of Wireless Sensor Network (WSN) are increasing. Current trends show that the Wireless Sensor Networks will be an integral part of our lives, more than the present-day personal computers [1][2][3].

Usage of Wireless Sensor Networks with low energy demands, low weight and intelligent networking features seems to be the most cost effective solution for many application areas. These devices incorporate wireless transceivers so that communication in short distances over a Radio Frequency (RF) channel is enabled. Wireless Sensor Networks can be used for many applications in various application fields such as automation of the buildings, machines, in the monitoring product quality or conditions at agriculture, medicine, and healthcare.

A general overview of available wireless solution targeted to the small home automation applications and their main parameters and limitations is described in Section II. Following chapter defines test cases and issues of testing of the wireless communication platforms. Statistic tool and evaluation method is described in the Section IV followed by the measured results in Sections V and VII. Conclusion of final measured values and their short assessment is in the last Section VII.

II. STATE OF THE ART

There are available different wireless communication solutions from different vendors on the market place. These solutions support different network topologies. Many of them are based on 802.15.4 [4] standard defining Physical Layer (PHY) and Media Access Layer (MAC) for Low Rate Wireless Personal Area Networks (LR-WPAN). In most cases they work on non-licensed wireless communication bands.

Probably, the most known standardized protocol that works on non-licensed bands is Zigbee [12]. It is a solution based on the IEEE 802.15.4 standard prepared by the Zigbee Alliance [5]. This standard was developed by consortium of industrial companies especially for building automation [6][7]. There are also special applications for industrial control, e.g., [8] [10] on remote access to the system and using small, independent wireless devices, [9][13][14] on building automation and telemetry applications, or an alarm system suitable for pervasive healthcare in rural areas [11]. Among the proprietary solutions, reference can be made to the technology of MiWi launched by Microchip Technology Inc. [15]. MiWi is based on the aforementioned standard but simpler than Zigbee from the implementation point of view. This technology does not support direct cooperation with Zigbee devices. From other solutions available on the market, mention would be made, for example, of the solution promoted by Z-wave alliance [16][17].

These solutions have disadvantage in attempt on being a universal solution targeting every kind of applications. It brings heavier protocols, more difficult and more expensive implementations, lower reliability, and increased network complexity.

Effectiveness of Wireless Sensor Networks (WSN) relies on the communication parameters of interconnected sensors' nodes, which are typically transmitting power, baud-rate, error-rate and their detection range or sensitivity to received signal.

These WSN technologies are determined especially for monitoring environmental and physical conditions, such as temperature, pressure, sound, vibration, humidity, and motion. WSNs applications are often used to perform many critical tasks and sensor networks applications have to meet strict rules and parameters to reliably and error-rate.

A failure of a component or components of a network can result to malfunction in the area of sensing, data processing, and communication. From this point of view it is necessary to evaluate the availability and reliability of application services as two important dependability factors [3].

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III. Test Case Description and Problem Definition

Small battery operated wireless sensor nodes are in our network used for automatic inventory system. This application not only expects wireless signal coverage but also need undisrupted service and reliable connectivity. The key aspect of wireless channel is the monitoring and evaluation of the channel quality. Most of the models of radio wave propagation involve questions related to the "free space" radio wave propagation [18].

Radio waves emit from a point source of radio energy, traveling in all directions. Obstacles such as physical and structural components of a building, furniture and fixed or movable structures, or the ground can impact signal propagation paths. Especially ferrous materials, such as steel and iron, can drastically alter signal propagation characteristics, communication distances, link quality, and many other factors [19].

Reflection, diffraction and scattering cause radio signal distortions and give rise to signal fades, as well as additional signal propagation losses. Indoor use of wireless systems creates the necessity for evaluation of indoor radio (RF) propagation. Any obstacles in the pathway would be harmful to RF transmission, radio signals penetrate of obstacles in ways that are very hard to predict. The final composite signal is made up of a number of components from the various sources of scattered and diffracted signal components or reflections from different directions.

To better understand this effect in our test case we at first evaluated the communication characteristics when sensor nodes were placed in various locations and distances. Absorption of RF energy results in loss of signal strength and reduced transmission distances. RF signals from wireless sensor nodes are air radiating from a transmitter and propagating through a medium in all directions. We need to understand the communication distance of individual nodes as well as to evaluate how and where to install the nodes.

The WSN in this application test case is based on the IQRF wireless communication platform for industrial and home automation. This is the technology that was specifically developed for wireless sensor mesh networks by Microrisc company [20]. Typical application scenario of home automation with IQRF communication technology for a smart house is shown in the Fig. 1. The main parts of the platform are covered by Czech and US patents [21][22][23]. For our experimental purposes, the standard IQRF components and development tools have been used. This wireless solution could be used for wireless connectivity necessary for telemetry, remote control, displaying of remotely acquired data, connection of more equipment and building automation. Implementation of IQRF transceiver modules works in non-licensed communication bands, license-free ISM bands 868 MHz in EU, 916 MHz in US, 433 MHz in EU, US and other countries.

Basic features of the IQRF communication platform are especially extra low power consumption (1 μA in the sleep mode and 35 μA in the on-line mode), available networking functions, programmable RF power up to 3.5 mW, SW selectable in steps, up to 170 m communication range, 15 kb/s (optionally 100 kb/s) RF bit rate. A transceiver module is the basic communication component needed for realization of wireless RF connectivity and can work as a node or a network coordinator. The IRQF modules could be integrated into any electronic device via SIM card connector. The low power consumption predetermines these modules for battery powered applications. The transceiver module is equipped with the IQRF operating system supporting functionality for the user application. There are RF functions for transmitting, receiving, network bonding, routing, main parameters configuration, EEPROM access functions, and IIC and SPI communication functions. Data processing, for example, encoding, encryption, checksums, adding headers, is evaluated automatically by IQRF operating system during the communication. The other functions of operating system are three buffers and some other auxiliary functions. IQRF operating system is buffer-oriented and allows sending up to 32 bytes in one packet.

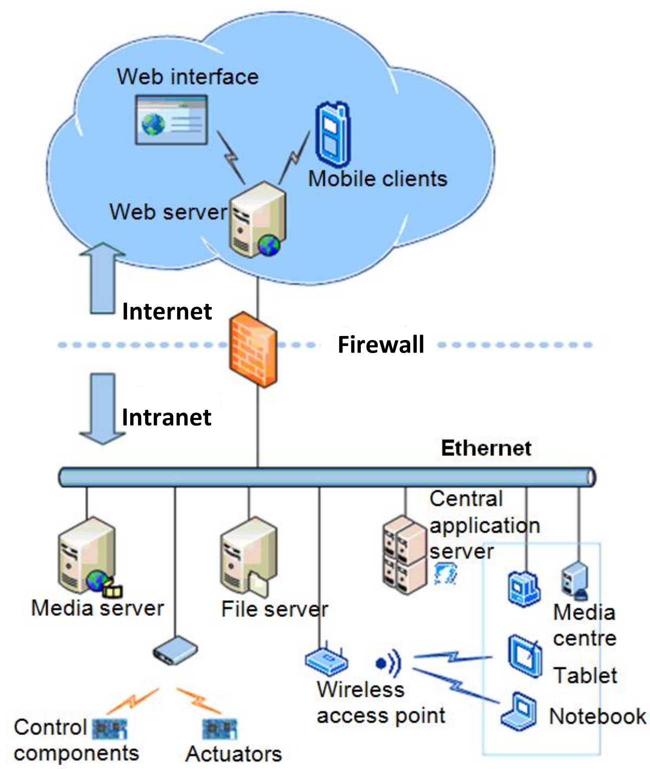

Figure 1. Block diagram of the telemetry and control for smart house

This application test case demonstrates simple data collection from wirelessly connected sensors. The network used for our experiment consists of one coordinator and a set of communication units. This is the basic star network topology where a sensor network is created around a core coordinator. The packet is wirelessly sent by operating system to the coordinator and the quality of the communication is statistically evaluated.

IV. Test Cases and Used Data Evaluation Method

For wireless communication parameters measurement were used two basic tests-case scenarios. The first one examined communications' parameters and wireless technology limits under typical building environment with the set of rooms separated by the plasterboard walls and the second set of measures was done in the long hall without any physical obstacles to test free space signal propagation.

A. Statistical description of the wireless network stability

The binomial distribution $B(n,p)$ with parameters n and p gives the discrete probability distribution of independent observations by the number of observations in the group that represent one of two outcomes. This distribution describes the behavior of a count variable X if the number of samples n is fixed, each sample represents "success" or "failure", each sample is independent, and the probability of "success" p is the same for each outcome.

The binomial distribution gives the approach to dependability evaluation for wireless communication. We expect that in the stable wireless network each type of outcome has a fixed probability and by evaluation of the proportion of individuals in a random sample we could evaluate the stability of the network. They are the sequences of independent transfers in the communication model with two possible outcomes ("success" or "failure").

B. Statistical description of the wireless network stability

We extract samples of a certain size from the ongoing Wireless Sensor Network in our case study related to the stability testing of the channel quality. There are the sequences of independent transfers with two possible outcomes ("success" or "failure") in this experimental situation. The fraction or proportion of "failure" items can be expressed as a decimal or as a percent (when multiplication by 100 is used).

From the statistical point of view, the number of failures is the random variable. Common-causes and special-causes are the two distinct origins of variation in a system. Common-cause variation is the noise within the system and is inherent to the process. It could be removed by making modifications to the process. Special-causes are unusual, not previously observed variation, which is inherently unpredictable. There are only common-causes in the stable system and the statistical monitoring and control could be used for stability evaluation.

Each run that is accomplished is then a realization of a Bernoulli random variable with parameter p. The binomial distribution $B(n,p)$ with parameters n and p gives us the discrete probability distribution of these independent observations. If a random sample of n units of transfer realization is selected and if k is the number of units that are nonconforming, the k follows a binomial distribution with parameters n and p according to following equation

$$P(k) = \binom{n}{k} p^k (1-p)^{n-k} \ \ \forall k; k = 0,1,\dots,n \qquad (1)$$

We expect that in the stable wireless network each type of outcome has a fixed probability and by evaluation of the proportion of individuals in a random sample we can evaluate the stability of the network in setting condition. For the stability evaluation can be used the np-chart as Shewhart control chart with underlying binomial distribution. The sample size is constant and the number nonconforming is plotted against the control limits. The control limits are defined as a

$$n\bar{p} \pm 3\sqrt{n\bar{p}(1-\bar{p})}, \qquad (2)$$

where n is the sample size and $\bar{p}$ is the estimation of the long-term mean. Rational subgroups for our testing are composed of the transfer of packets under essentially the same experimental conditions.

V. Stability evaluation of indoor RF propagation (the test case of more RF propagation obstacles)

In this application test case, there were five transmission units in five various rooms each separated by the plasterboard partitions. There are two changed factors in this experiment: eight various levels of transmitting power and the daytime. In each run, there was 80 data transfer execution, which each consists from 500 data frame. The number of failures in the communication was then evaluated. The results from this first experimental test case are summarized in the Fig. 2. There are two factors influencing the results. The mark (a) in the graph highlights the independence of the number of failures on the RF power. For the distance that is higher than 5 meters it is necessary to optimize the RF power value. The mark (b) in the graph highlights the special-causes variation. Experimental results were evaluated by using the np control charts (see Fig. 3 and Fig. 5). An np-chart is a plot of the number of defective items observed in a sample where n is the sample size and p is the probability of observing a defective item when the system is in control without affection of special cause variation. The observed number nonconforming (NP) is plotted against the control limits (UCL – Upper Control Limit, LCL – Lower Control Limit), which are statistically determined.

For the purpose of statistical evaluation of this wireless communication, experiments were used np control charts. The results of this analysis are summarized at the control charts (Fig. 3 and Fig. 5). The fluctuation of the points between the control limits (UCL, LCL) is due to the common cause variation. Any points outside the control limits related to the six standard deviation rule could be attributed to a special-cause variation. There are some cases where special-causes are affecting the results. Out of control points are marked as “1”. Overall interpretation of created np control charts for this part of experiment leads to these conclusions:

- The higher distance between the transmitter and receiver is in the relation to the special-cases variation existence and communication failure.

- The higher RF power gives the higher probability for wireless communication without failures.

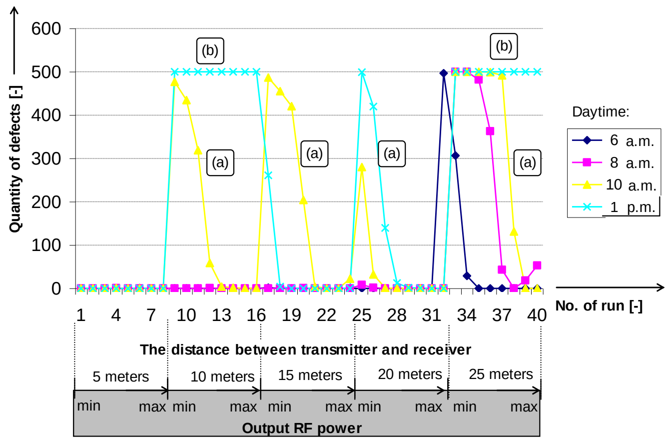

Figure 2. Wireless stability evaluation (the test case of more RF propagation obstacles)

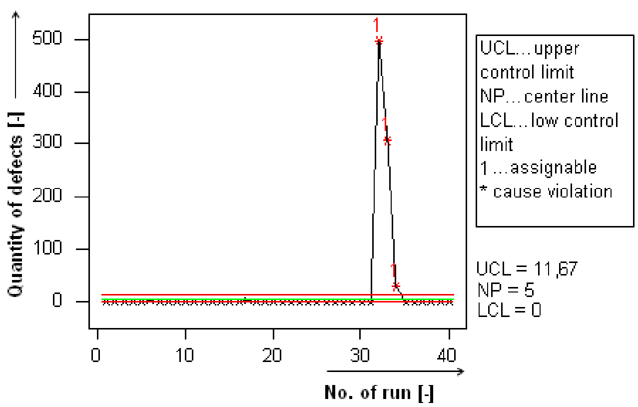

Figure 3. NP chart of wireless stability evaluation for the measurement at 6 p.m. (the test case of more RF obstacles)

VI. STABILITY EVALUATION OF INDOOR RF PROPAGATION (THE CASE OF THE FREE SPACE RF PROPAGATION)

In this part of the experiment, there were five transmission units in five various places in a region, which is free of all objects that might absorb or reflect radio energy. Eight various levels of the RF power and the various daytime are changed in this experiment. In each run there was 80 data transfer execution, which each consists from 500 data frame. The number of failures in the communication system in this configuration was then evaluated. The results from this part of experimental test case are summarized in the Fig. 4.

We could see that there are some communications problems related to the setting of the RF power. The RF power needs the optimization according the distance between the transmitter and receiver. These situations are in the Fig. 4 depicted by mark (a).

Communication with the fifth transmitter unit located in the distance 25 meters for the receiver is affected by special cause variation in this case. This is the limiting distance that the signal is able to penetrate at the building environment in this experiment configuration.

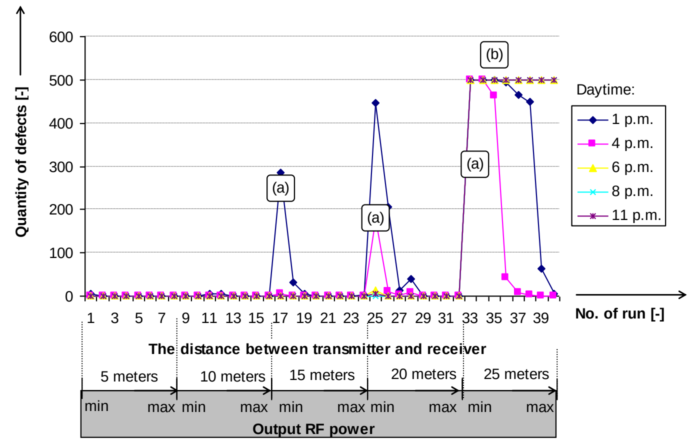

Figure 4. Wireless stability evaluation (the test case of the free space propagation)

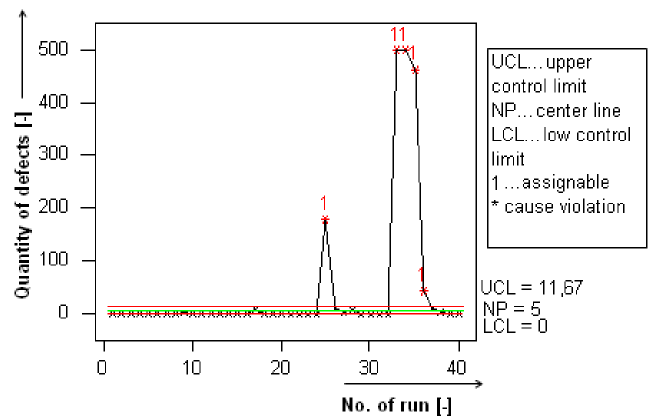

Figure 5. NP chart for wireless stability evaluation (the case of the free space propagation, 4 p.m.)

The mark (b) in the Fig. 4 is related to the communication failure and the special cause variation case.

The number of communication problems in comparison to the case of more RF propagation obstacles is smaller. The requirements for higher RF power are smaller and the overall stability is better. The higher RF power gives the higher probability of wireless communication without failures.

VII. CONCLUSIONS

IQRF is a new wireless communication platform especially designed and developed for specific requirements from home automation and telemetry. One of the main aims was to offer wireless platform to developers of the end user devices that allows rapid development without necessity of stack implementations. As a typical representative of the low-cost wireless communication technology IQRF presents ideal solution for home automation and office or light industry applications. As such, this platform was designed especially for home automation and telemetry applications.

Proposed test cases have proved suitability of this technology to typical application scenarios, test their real communication parameters under buildings environment and determine limits. Based on the statistical result of measured data analysis can be set optimal node distance and output RF power to communication defects ratio. Output RF power influences power consumption and then operation time. Optimal combination of distance and output RF power in specific operation conditions under different environments is therefore highly needed and can significantly improve operation time and minimize communication failures.

Real tests proved wireless communication abilities of IQRF, which fits to the requirements for usage in home automation and telemetry applications and also in the currently developed automatic stochastic system.

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