QUALITY OF SERVICE OF WSN AS DETERMINATE FACTOR OF SUSTAINABLE AUTONOMOUS BEEKEEPING SYSTEM

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Abstract:

The modern autonomous beekeeping system developed in this research is the real example of Internet of Things technologies (IoT) in the beekeeping sector. It performs a bee colony control without interfering with its processes, while optimizing frequency of the apiary inspection. The system helps to analyze data correlation with video, meteo data, mass changes in time as well as interpretation of nest temperature, humidity and linking to local geographic and biological conditions. It allows a beekeeper to request and receive key data indicators. The Quality of Service of Wireless Sensor Networks is a determinative factor of a resilient Autonomous Beekeeping System. This research explores the problems associated with vulnerability of Wireless Sensor Network with the special focus on the weather conditions impact on the signal transmitting quality in WSN. The study of the impact of weather conditions on the signal strength in outdoor wireless sensor networks, testing the reliability of data transmission, alerting services performance degradation in different weather conditions was implemented in this research based on the WSN testing results.

Keywords:

wireless sensor networks - WSN, Quality of service (QoS), vulnerability, MQTT, autonomous beekeeping system.

1. INTRODUCTION

Nowadays a beekeeping is based largely on manual work that requires regular visits to bee apiaries for monitoring bee hives. However, physical inspection interferes bees' life and causes stress that negatively affects the productivity of all product lines. It is very important to find opportunities for remote monitoring of bee hive' profitability, flying activities, bee colony moods and bees' family health status. By implementing the autonomous beekeeping, the hives conditions can be tracked remotely, e.g. whether the inside temperature is critical, if the family is missing feed, therefore the critical deviations can be detected and prevented in time.

The project "Autonomous Beekeeping" was initiated by the Riga Technical University, Latvian Internet Association and two beekeeper farmers in the beginning of 2018. The project is funded by the European Agricultural Fund for Rural Development Program 2014-2020 Cooperation: Support new products, methods, processes and technologies.

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The proposed solution is the real example of Internet of Things technologies (IoT) implementation in the beekeeping sector. It will perform bee apiary control (individual bee colonies and at the apex level) without interfering its processes, while optimizing frequency of the apiary inspection. The system will help to analyze data correlation with video, meteo data, mass changes in time as well as interpretation of a nest temperature, humidity with the linking to local geographic and biological conditions. It will allow a beekeeper to request and receive key data indicators. At the second stage of the project, the use of alternative energy sources (solar) for power supply will increase the application possibilities of the system at variety of geographical locations.

During a summer season beekeepers are forced to reallocate a bee apiary several time pursuing better conditions for harvesting of honey products. This fact sets requirements to the autonomous beekeeping system: a wireless network, which ensures data collection from sensors, has to be easy and fast setup, independent from an electricity supply, reliable, safe and independent of weather conditions (rain, fog, froze, etc.)

The goal of the research is to test the quality and reliability of the WSN network, which is used for a bee hives monitoring system. This research explores the problems associated with vulnerability of the WSN, with a special focus on the weather conditions impact on the signal transmitting quality. The study of impact of weather conditions on the signal strength in outdoor WSN, testing reliability of data transition, alerting a service performance degradation, the data transmitting joint concept in different weather conditions was implemented in this research, based on the WSN testing results.

2. HOW WEATHER AFFECTS WIRELESS SIGNAL

The paper [1] analyzed the potential impact of rain, fog, wind and temperature deviations on the performance of a network equipment of wireless networks. Gathering information about network throughput, error rates etc. on a daily basis it was revealed that "different weather phenomena affect the wireless links in a variety of ways". Their experiment showed that wind storms cause movements in the antenna and consequently make the antenna skew. Moreover, it was proved that high temperature causes the output waveform to distort that results in errors in the packet processors in the routers.

Previous studies have shown that absorption, scattering, and refraction of microelectromagnetic waves by atmospheric gases and precipitation is an important limiting factor in transmission distances in wireless communications. In fact, rain, fog, and clouds become a significant source of attenuation when wireless networks operate using the microwave spectrum [2].

Quality of service (QoS) provisioning in communications systems entails a deep understanding of the delay performance. The delay in wireless networks is strongly affected by the traffic arrival process and the service process, which in turn depends on the medium access protocol and the signal-to-interference-plus-noise ratio (SINR) distribution. The paper [3] characterizes the conditional distribution of the service process given the point process in Poisson bipolar networks. The researchers analyzed the delay performance under statistical queueing constraints using the effective capacity formulation. They identified the impact of QoS requirements, network geometry and link distance on the delay performance.

The research [4] investigated a metering solution based on the modular principle for inter-system communication paradigm using selectable interface modules (IEEE 802.3, ISM radio interface, GSM/GPRS). They focused at EMI electromagnetic interference impact at the proposed solution, which should be applied to the control of different critical infrastructure networks (water distribution and district heating networks, electricity network, etc.) using adapted modules. Therefore, the developed metering systems has to be able to operate under diverse conditions: outdoor installation, indoor industrial installations; under electromagnetic pollution, temperature, humidity, rain impact, etc.

The most common formula for estimating the absorption due to rain, according to which: A = aRb, where absorption is measured in decibels per kilometer, rain intensity is measured in millimeters per hour, and parameters a and b depend on the size distribution of the droplets and on the frequency. Moreover, the absorption also depends on the polarization of the electromagnetic wave. For certain values of a and b, the absorption depends on the intensity of rain, R. The main concern is about the periods of time during which the intensity of rain exceeds a certain threshold. It all depends on the climate zone. There are tables developed by the International Telecommunications Union (ITU), where the Earth is divided into 15 climatic zones depending on precipitation. According to the tables R, values are exceeded for different periods of time during the year. This information can be used to determine the availability of a radio channel [5].

The fog affects similar to rain due to much more smaller droplets. The impact of fog to a wireless signal reception depends on a frequency range used for operating. Below 2 GHz it's not a huge factor, but above that number fog can seriously scatter the signal. If we talk about cell signal, some of the latest 4G LTE bands operate at those frequencies.

Ice crystals are far less dense than liquid water, especially in snowflake form, so they don't have nearly the same effect on signal propagation. But very heavy snow may still refract radio waves, reducing signal strength.

The high frequency wavelengths used by phones don't travel well through *water, b*ecause water conducts electricity that can reflect radio waves. Water vapor absorbs the energy of radio signals, and turns them into heat. Basically, water blocks the radio signal between the tower and mobile phone. There is no or few obstructions to radio signals traveling across bodies of water, however, cool water temperatures can create surface inversions that trap a layer of cool air close to the surface. Both factors together may mean you'll experience longer than usual reception ranges between two points separated by a body of water.

The impact of *hail* on the quality of services depends on the size and density of the hail in question. Ice has less dense than water, and hail does not tend to fall as thickly as rain, so its refraction of cell signal will be less. The huge charge of a *lightning bolt* can cause electrical interference, and can damage antennas, power sources, and other transmission equipment. *Wind* alone does not interfere with radio signals, but the weather conditions associated with it can do it. Wind can damage exposed cell towers, power lines, and the electrical equipment associated with them.

The dense biomass of a forest contains a ton of water, so the *trunks and leaves of trees* combine can reflect and absorb radio signals. In a deciduous forest, you may get better signal reception in winter than in summer, due to the trees shedding their leaves, opening up space for radio transmissions to pass through [6].

The sustainability issues of autonomous beekeeping have been considered in [7, 8, 9] with the research focus on bees behavior in different environment condition. In our research we put emphasis on the development of a reliable monitoring system, which is resilient against changing weather conditions.

3. AUTONOMOUS BEEKEEPING SYSTEM

Wireless Sensor Networks (WSN) are widely used for implementation of Internet of Things (IoT) concept at the different areas of application. The validation of reliability of data transmission can be implemented by alerting a service performance degradation. The data transmitting in different weather conditions have been tested because, it is an important part of the whole Autonomous beekeeping system.

The wireless sensor networks operating outdoors usually are exposed to changing weather conditions, which may cause severe degradation of a system performance. The main impact at the quality on WSN is assessed by Quality of Delivery (QoD) parameters. QoD can be characterized by error recovery procedures, packet loss, retransmission process, data processing, flow control, and integrity of data. The metrics used to link quality estimation in WSNs are RSSI (Received Signal Strength Indicator), PRR (Packet Reception Ratio), SNR (Signal to Noise Ratio), and LQI (Link Quality Indicator). The quality and reliability of WSN network was tested as a part of bee hives monitoring system (see Fig. 1. – sensors and video cameras and Fig. 2 – meteostation and autonomous energy supply).

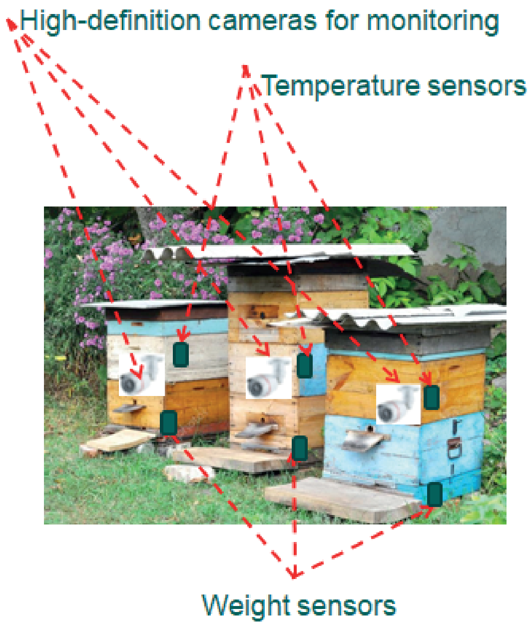

Fig. 1. Sensors and video cameras installation at bee hives

At the project "Autonomous beekeeping", the Riga Technical University in cooperation with two beekeeper farmers and Internet Association has created a unique autonomous beekeeping technology, based on IoT approach, used to monitor bee gardens remotely.

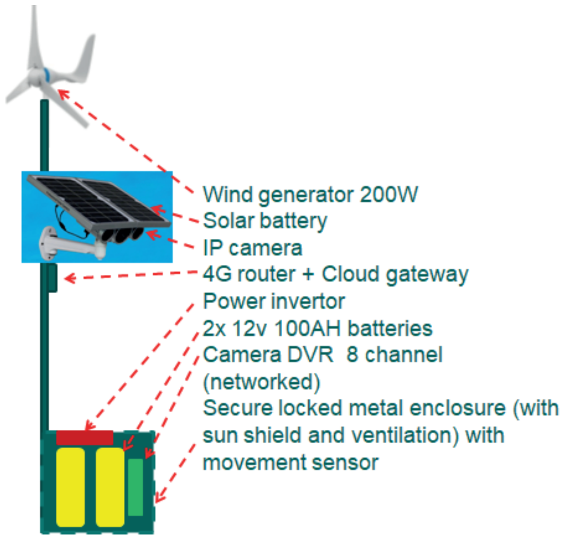

Fig. 2. Autonomous energy supply for smart monitoring

We tested separate elements of the "Autonomous Beekeeping" system installed at five bee hives in really field conditions – Riga Botanic Garden. During testing, the weight of bee hives, as well as the temperature sensors, which measure temperature ambient temperature and the temperature inside of the beehives, were monitored. Fig. 3 depicts the autonomous beekeeping systems organization scheme.

Electrical power consumption of both common and individual elements of the equipment (Fig.2) was measured and monitored at the first stage. However, now we can only theoretically calculate productivity of PV elements for autonomous power supply, since the power consumption after launching of additional measurement equipment and weather stations at the next phase can be predicted based on equipment suppliers' information.

The beehive monitoring system deployed a Node-RED [8] as a gateway concentrator for wiring together hardware devices (temperature, weight, humidity sensors), APIs and online services. At the heart of Node-RED is a visual editor allowing complex data flows to be wired together with only a little coding skills. Node-RED main functionality is to decode and to route MQTT smart metering data to further service orchestration or use in external services as monitoring system or external clients (see Fig. 3).

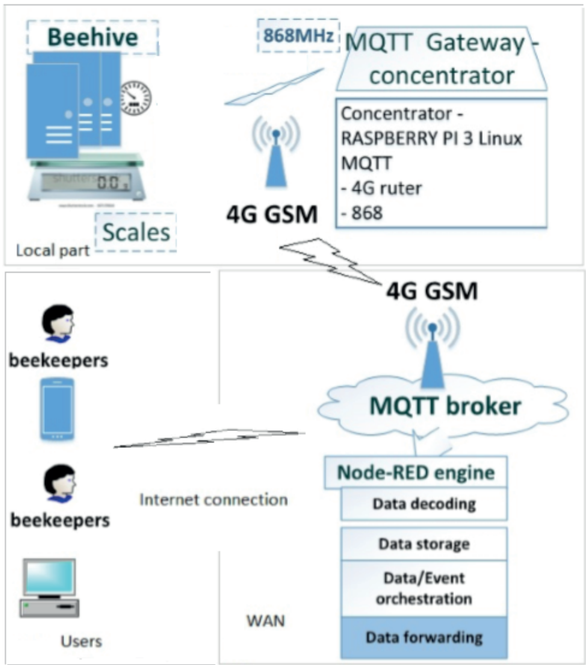

Fig. 3. Test bed layout: beehive monitoring system

The 4 G highly reliable and secure LTE router with I/O, GNSS and RS232/RS485 for professional applications was used for communication between gateway-concentrator and MQTT broker. Router delivers high performance, mission-critical cellular communication and GPS location capabilities. RUT955 is equipped with connectivity redundancy through dual SIM failover. An external LTE omnidirectional antenna connectors makes it possible to attach desired antennas and to easily find the best signal location. Radio chip - semtech sx1231H, SMA antenna, data encryption standard AES-128 is used.

There are 3 surface sensors-transmitters for measuring of temperature inside of a hive in 3 different locations, in the center and sides (Fig. 4) and 1 sensor outside the stack (Fig. 5) to get the outdoor air temperature are used for one beehive. The weight of each hive is measured by specially designed weight platform (Fig. 4) and are sent by a sensor-transmitter to the concentrator without processing.

Fig. 4. Measuring of temperature inside hive

The measurements from sensor-transmitters are transmitted to concentrator from sensors using ISM range signal. For example, weight sensor 1C3003AE0030 transmits data via radio gateway-concentrator. The application MAC CoolTerm has been used to process signals and create tables with data, in the output of data transmitting.

Fig. 5. Outdoor temperature measurement

The message (telegram) looks, for example: 01.01 00:04:40 42 0B 1C3003AE0030 0337 002580. The telegram shows the time, which started from synchronization of time in format mmhhmm.ss. RSSI LENSN03 (telegram counter), 37 (battery level) and at the end 002580 is a data read out from the balance 25b0 hex2dec9640) related the weights with 10kg load (55d0hex2dec21968). The hive weight is calculated in specific measurements, sing the output data from the sensor - transmitter.

The temperature sensor-transmitters transfers data to the server-broker every 15 minutes; the weight sensor transmits data to the server every 5 minutes. All data collected on the MQTT broker are displayed in graphical form. The users interpret data in graphics and as "dashboard" form, based on their own experience and understanding of ongoing processes in the hive.

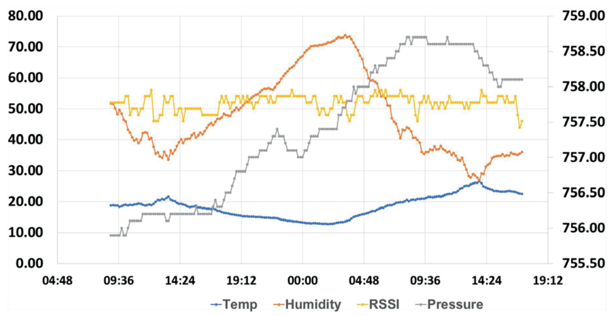

Fig. 6. Environment factor and RSSI Correlation

The weather impact on the tested system was assessed, by comparison RSSI data and the weather conditions data from the Weather monitoring system of Botanical garden in Riga. Environment factor and RSSI correlation during the summer period was analyzed. The weather impact, measured during summer period, was used as a reference for evaluation of Quality of Delivery (QoD). A snapshot of changing weather conditions is presented at Fig. 6.

The actual topology of WSN was defined based on the energy consumption level of nodes, distances between bee hives location points, and weather conditions at defined geographical location in order to assure reacquired level of Quality of Delivery (QoD). It is noticed that the largest impact at the RSSI data is provided by humidity changes, but less impact – by temperature and pressure variations. However, the system showed fair sustainability, due to RSSI data deviation happened within the normal range.

In order to process and interpret results a prototype of MQTT broker and the data collection and transmission system was tested as a part of autonomous beehives system. We deployed a Node-RED as an orchestration tool for wiring together hardware devices, APIs and online services. For further data processing, monitoring and interpretation an Emoncms code base is used. Emoncms represents measurement data as a dashboard and as the charts. The print screens show the temperature inside and outside of beehives, and deviations of beehives weight (see Fig.7).

It was noticed that the bees maintain a constant ecosystem within +/- 0.5^{0}C at the center of the beehive. The absolute mean value is 34.8^{0}C that really differs from the classical assumption.

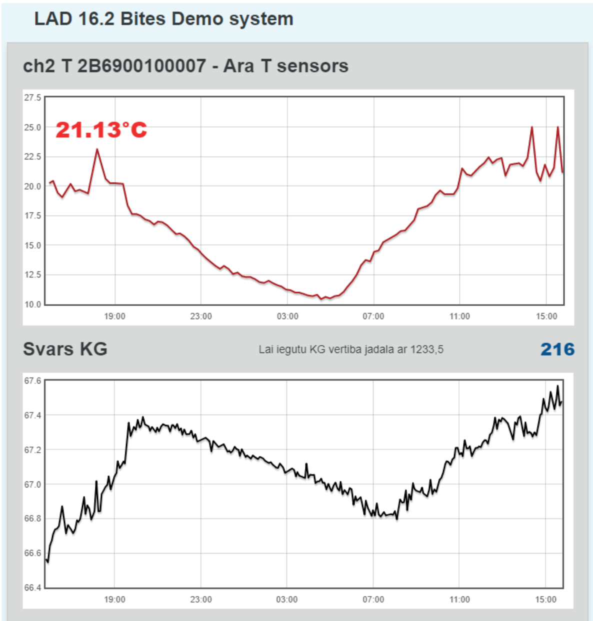

Fig. 7. Web based interface of on-line published monitoring results. Measurements of the temperature inside and outside of beehives, and weight deviations

4. CONCLUSIONS

Development of autonomous beekeeping system is still in progress, since the project team implemented the first stage of the project. Recent achievement of IoT provide good opportunities for Implementation of IoT principles in autonomous beekeeping for creation reliable system, which is resilient to the weather conditions.

The offered autonomous beekeeping system applies sensors that provide useful data on hive status (internal and ambient temperature, humidity, weight of the hives). Such sensors provide important data to the users, so they can evaluate the hive and take further action.

3G technology is used to transmit the sensor data from the hive to the user's phone or computer, because it provides stable, secure and relatively fast data transfer. Furthermore, availability of GSM connection in all parts of Latvia promotes its application at autonomous beekeeping system.

Meteo-data were used to evaluate correlation between measured weather parameters and deviation of the parameters, which characterize QoS of WSN. The assessment of data quality, based on experimental data was done. The quality and reliability of WSN network was tested using bee hives system's monitoring tools.

It has been concluded that the described intelligent beehives system can be improved with additional sensors and various actuators. At the second stage of the project video monitoring system will be introduced as a part of the system. Additional research is planned in order to ensure autonomous energy supply, so it is necessary to evaluate consumption of energy and opportunity to apply alternative energy sources, such wind and photovoltaic elements.

The developed solution could be considered as TRL 5 level, however, for the future commercial use, the data reliability is recognized as one of the critical points. The measurement accuracy and data quality from the testing network are in a line with the initial forecasts. The frequent reading of weight data opens the way for analyzing ongoing steps at a more detailed level than originally anticipated. The use of intelligent bee hives system increases bee productivity beekeepers work easier.

ACKNOWLEDGMENT

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