SHORT TERM SCIENTIFIC MISSION (STSM) SCIENTIFIC REPORT

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This report is submitted for approval by the STSM applicant to the STSM coordinator

Action number: CA15127 “Resilient communication services protecting end-user applications from disaster-based failures" (RECODIS).
STSM title: Adaptive Network Topology modelling for resilient WSN system
STSM start and end date: 2019-04-09 to 2019-04-17
Grantee name: Nadezda Kunicina

PURPOSE OF THE STSM:

The STSM explores the problems associated with Adaptive Network Topology modelling for resilient WSN system, with special focus on the weather conditions impact on the signal transmitting quality in WSN. The STSM aimed to finalize preparation of subsection in a chapter of the Action final book, regarding wireless sensor networks operating an re-configuration in case of network non availability by outdoors/changing weather conditions and drying of autonomy power supply, the analysis of network topology and modelling of possible solutions where provided and modeling of system topology was done, based on Quality of Service requirements. The main motivation of STSM was to complete subsection of 3.2. Vulnerability of Wireless Sensor Networks and 4.2. Re-configuration of a Network Topology and Re-routing Mechanisms in the RECODIS book chapter 2.6. Role of Quality In Wireless Communications Under Weather-Based Disruptions. Current topic of STSM: "Adaptive Network Topology modelling for resilient WSN system" fits the WG2 - Weather-based disruptions. The STSM aimed to finalize preparation of subsection in a chapter of the Action final book, regarding wireless sensor networks operating in outdoors/changing weather conditions, the analysis of testing results, and correlations, which causes severe degradation in system performance, are described. the RTU and KTU teams where prepared common publication and are cooperating together in joint chapter preparation, related with COST RECODIS WG2.

DESCRIPTION OF WORK CARRIED OUT DURING THE STSM

First of all, during the STSM, the collection of the information (based on literature, scientific publications, experience obtained by Kaunas University of Technology) for providing the research in the field of Adaptive Network Topology modelling for resilient WSN system to various weather-based and external factors was done. The power supply reliability and re- configuration of network topology for long life of WSN was analyzed. Results of this STSM are included in the chapter 2.6 Role of Quality In Wireless Communications Under Weather-Based Disruptions, subsections 3.2 and 4.2. Moreover, the RTU and KTU teams agreed to develop common publication and are cooperating together in joint chapter preparation, related with COST RECODIS WG2 (Weather-based disruptions focusing on the end-to-end transmission continuity solutions) tasks.
The network reliability is critical for assurance of autonomous system stability, that's why the detection of signal quality degradation in on-field monitoring systems is crucial, the impact of power supply disruptions was modelled and described in subsection 4.2, as result was agreed, that the power supply for autonomous wireless sensor network nodes is crucial to reliability issue for stability of the data transmission solutions, the degradation of WSN quality due to the power transition factor, including low battery level was re-described in subsection 4.2 of the chapter.
The weather impact on the tested system was assessed, using RSSI data and battery drying was modelled, based on the Antonyms beekeeping system in Botanical garden in Riga. The KTU team proposed algorithm for re-routing of data transmitted over WSN, and this algorithm was tested, using real measurement data and results from power supply degradation model. The weather impact on a battery drying was used a reference for evaluation of Quality of Service (QoS). The temperature data at the center of the hole confirms that the bees maintain a constant ecosystem. The results are described in subsection 4.2 of the chapter. Development of methods for recognition and mitigation of

battery drying in WSN systems, like technologies for construction of measuring instruments, as well as the reconfiguration issues was modeled in cooperation with KTU. The re-routing technique of data over WSN network, due to the weather impact on battery and degradation of signal and non-acceptable of Quality of Service (QoS) parameters, were modelled as well during this STSM.
Based on the obtained results, the drafting of two articles in Quality of service for distributed Quality monitoring solutions as well as The UAV application for the QoS assurance in distributed networks where discussed., and now are in the preparation process in cooperation with KTU team.

DESCRIPTION OF THE MAIN RESULTS OBTAINED

The STSM mission was dedicated to the progressing of the joint chapter of the action final book. The actual draft of 3.2. and 4.2 subsections is uploaded in Overleaf platform and added to this report as an annex. Weather-based impact on battery reliability and network re-configuration focusing on the WSN network testbed was analyzed.
The number of laboratory measurement sets and modelling of results was done.

FUTURE COLLABORATIONS (if applicable)

There is planned a significant common work as in research, as in academic field between RTU and KTU.
We will work in order to finish the joint chapter 2.6.

We will work on common articles and we will submit them to the presentation as well as publication in the international conferences.

In addition, we are working together in order to submit common project in the field of education for future collaboration in academia and research challenges.

Environmental Conditions Mitigation by Application of Quality-driven Techniques to Improve Wireless Communications Resilience

Rasa Bruzgiene; Lina Narbutaite; Tomas Adomkus; Peter Pocta; Peter Brida; Juraj Machaj; Erich Leitgeb; Pirmin Pezzei; Hristo Ivanov; Nadezhda Kunicina; Anatolijs Zabasta; Jelena Caiko and Antons Patlins

Abstract Heavy rain, dense fog or snow, extreme temperature and moving objects - represent a few examples of environmental conditions, which has a significant influence on a reliable communication over wireless networks. In particular, a wireless link is vulnerable to a variety of precipitation, amount of it and a level of its humidity as well as to fluctuations caused by reflections of signals from moving objects. This means, that wireless signal can experience so-called "path loss" or attenuation of signal strength in a face of environmental changes. It is worth noting here they can cause a serious trouble in a process of communication over wireless network or even a disruption of it. In this case, both critical changes in communication and its degradation are noticeable by users as well as network operators while service and network quality are evaluated by them respectively. A dependence of overall quality of communication on different quality parameters can be used as a suitable tool for effective resilience of wireless communications against the environmental disruptions. This chapter presents novel ideas how the quality parameters from different layers (network, transport, application) can be used for a creation of alerts if a performance of a service over wireless optical network is degrading, as well how

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data can be re-routed in a wireless sensor network and a wireless positioning system can be re-configured in a face of environmental disruptions. The authors have experimentally evaluated a vulnerability of wireless networks in different environmental conditions and their influence on an overall quality of communication over the wireless link. As a result of this, approaches of quality applications, as a technique to be deployed in a face of disruption of wireless communication network, are presented and discussed in this chapter.

1 Introduction

The resilience of the network and services relies on its preparation against various disruptions or even disasters, which can occur in the presence of internal and external fault factors [1]. Unreliable network functioning activities, management and provision of network services and applications or access of users and their behavior can be recognized as the internal factors. Meanwhile, natural phenomena or different weather conditions can be external factors that causes disruptions to a network activity or provision of services. When it comes to the disrupted network or service, the resilience solutions should help in provision of an acceptable level of service. The acceptable level of service is mainly defined by three sides [2]:

- considered as the acceptable to the user (*subjective evaluation of service level*);
- stated in quantitative parameters of a service, such as throughput, latency, packet loss, jitter, *etc*. (*evaluation of service level by objective measurements*);
- refined on the impact of a service disruption (*evaluation by the impact to a service user*).

It is obvious, that a correlation between subjective evaluation by a user and objective measurement of service parameters by the operator would give an effective way to determine the acceptable level of service in a face of network service disruption. The satisfaction of users by the provided service as well its quality is described by perceived service quality parameters. However, perceived service quality is composed of not only the network performance parameters, but also of the quality parameters such as reliability, availability, usability and fidelity. Such parameters can describe an extent of the impact on the network in terms of users or in terms of network recovery time and quantify a significance of the service disruption impact.

This means, that the subjective evaluation of service level and the scale of a service disruption are related to each other and this will be the first alert coming from users to a network operator when the network or service will be disrupted. An ability to evaluate a perceived service quality will give an operator some sense of the contribution of the network's performance to the overall level of the provided service. Moreover, it could serve as an alert in a reaction to disruptions and preparation of resilience mechanisms over a network. Due to this, quality parameters can be used as the 'an enabler' in developing the resilience solutions for the communication networks. This is particularly relevant when it comes to a wireless communication, which is very sensitive to the different environmental conditions, i.e. rain, snow, fog, temperature, moving objects, *etc.* [3][4][5].

An analysis of the impact of environment on various wireless communications has been done and resilient solutions have been proposed by different scientists. In [6] authors showed, that rain fading may bring significant network performance degradation of microwave backhaul networks. So they proposed a rain detection algorithm, aiming at efficiently distinguishing between long-term and short-term channel fading. The authors in [7] discussed an impact of weather-based disruptions on Millimeter-wave (71-86GHz) [8], micro-wave (3-30GHz) [9] and cellular GSM network [10] technologies. Other studies have focused on an impact of moving objects on a performance of wireless communication technologies, e.g. IEEE 802.11 [11], as well as a localization system [12].

However, nowadays an evolution of wireless technologies is accelerating, but there is unfortunately no common solution for the better resilience of wireless communications in a face of different environmental conditions. A question how to avoid faults and disruptions in wireless networks/communication and if environmental conditions are becoming a threat to their/its functioning is still open. The question remains to be open in relation with the upcoming 5G and beyond technologies [13], where wireless links plays a main role in a data transmission.

So, there is a challenge to provide a reasonable quality using unreliable wireless communication as it is affected by external factors in all layers, i.e. physical, data link, network, transport and application layer. In this context, the quality parameters (from all the layers) and solutions how they will be evaluated (objectively, subjectively, or correlated) can be used to prevent a disruption of a network or service, early warning (alarming) and preparation for potential failure. Due to this, the aim of this chapter is to present novel ideas how to use quality parameters for alerting a service performance degradation, re-routing of data and re-configuration of a network for different wireless communication technologies in a face of environmental disruptions.

The chapter is organized as follows. Section 2 describes a basic definition of quality, its classification over OSI model and correlation in the context of the resilience of telecommunication networks and systems. Section 3 is based on the experimental investigations and shows an impact of the different environmental conditions on wireless optical network (FSO), wireless sensor network (WSN) and modular wireless positioning system. This section serves as a basis for section 4 and provides an initial data for developing new approaches in quality applications under the environmental disruptions. The obtained results and recommendations are presented in Conclusions.

2 Background - Meaning and Position of Quality

A definition and meaning of *quality* depends on the context, in which it is used and applied. Basically, *quality* means a characteristic, a feature or an attribute measured by someone to something. In other words, quality is the degree to which a set of inherent characteristics fulfills requirements. This term is also used to indicate the superiority of something or attest a high level of value on something. However, it is quite difficult to find a generic definition of *quality* in the telecommunication industry. Quality, as a term is quite broad, and its meaning in telecommunications is very dependent on where it is applied to (e.g. system, network, data or process) and what specific measures are used for it.

In relation with this, this section describes the general OSI-based classification of quality and a correlation between different quality aspects deployed in the context of the resilience of telecommunication networks and systems.

2.1 Classification of Different Quality Aspects

The meaning and position of quality in the telecommunication systems are easier to understand through a prism of the OSI (*Open System Interconnection*) standard [14][15]. The OSI-based classification of quality is presented in Fig. 6.

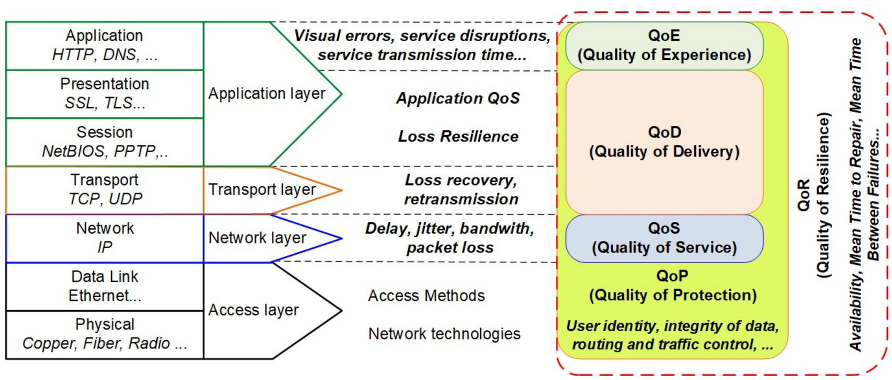

Fig. 1 OSI-based classification of quality in focus to resilience

As it is clearly seen from Fig. 6, the *quality* covers all the seven OSI layers - from the physical to the application layer and can be, in terms of the resilience of telecommunication networks and systems, classified into:

- Quality of Service (QoS);
- Quality of Delivery (QoD);
- Quality of Experience (QoE);
- Quality of Protection (QoP);

According to the ITU-T Rec. E.800 [16], **Quality of Service (QoS)** is defined as totality of characteristics of a telecommunications service that bear on its ability to satisfy stated and implied needs of the user of the service. It is worth noting here that the characteristics should be observable and/or measurable. When the characteristics are defined, they become parameters and are expressed by metrics. The QoS can be characterized by any QoS variable, e.g. delay, jitter, packet loss, etc., which is perceivable by a user.

On the other hand, the ITU-T Rec. P.10 /G.100 [17] defines **Quality of Experience (QoE)** as the degree of delight or annoyance of the user of an application or service. It results from the user's evaluation of the fulfillment of his or her expectations and needs with respect to the utility and/or enjoyment in the light of the user's context, personality and current state. When it comes to the context, an interactional, situational and socio-cultural context plays a role in this case.

Minhas et.al. [18] described **Quality of Delivery (QoD)** as the quality characteristics of data transmission process on the transport and application layers. Naturally, the QoD can be characterized by variables, which are involved in data delivery processes on the above-specified layers, i.e. error recovery procedures, packet loss, retransmission process, data processing, flow control, integrity of data, etc.

Quality of Protection (QoP) [19] gives us an ability to specifically measure and describe a security of the telecommunication systems or services. In other words, the QoP defines the characteristics of the system or service from a security operation point of view at the every OSI layer according to the security requirements. Such characteristics represent an access control, check of a user identity (authentication, authorization, etc.), data encryption, traffic control, physical-logical address mapping, routing, etc.

A characterization of the telecommunications network, system or service reliability can be done by **Quality of Resilience (QoR)** metrics. Generally, the QoR is a guarantee of a recovery after a failure occurrence. So it means, that the QoR also specifies a probability to have an available network, system or service. In this case, the QoR [20] includes variables from the QoS, QoD, QoE and QoP and can be expressed by such metrics as availability, Mean Time to Repair (MTR), Mean Time to Recover (MTR), Mean Time between Failures (MTF), etc.

2.2 Interrelation Between Different Quality Aspects

The quality position in the telecommunications can be described by an interconnection of different quality factors, that influence the overall service transmission process or the performance of the network or system. Figure 2 shows an interrelation between the Quality of Service, Quality of Delivery, Quality of Experience and their correlation with the Quality of Protection and Quality of Resilience.

The QoS is influenced by the parameters describing an infrastructure, i.e. a transmission system, and/or devices, which are involved in a service transmission chain. It has an influence on the characteristics covered by the Quality of Delivery. The factors, which influence the QoD, are mainly related to the communication process and data parameters. This means, that all the characteristics in the communication process, like routing protocols, path, data processing and recovery mechanisms im-

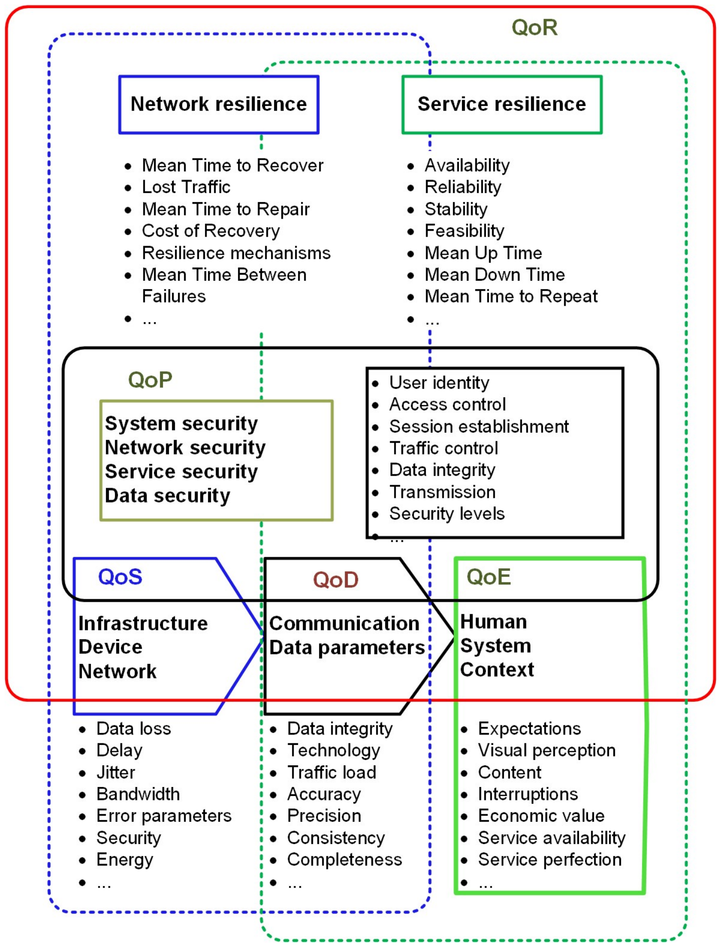

Fig. 2 An interrelation between the QoS, QoD, QoE, QoP and QoR

pact it.

The perceptual evaluation of the service quality, service completeness, cost/service ratio, etc., is done by the users of telecommunication networks or systems. Any degradation of the QoS and QoD characteristics can cause a significant impact on the expectations of the users on the application or service. Also, any vulnerabilities of the system or network impact the transmission of service or data. This can also create critical situations for the users, as it can cause an inevitable commercial or social problems for society.

It is worth noting here that the QoS and QoD characteristics correlate well with the parameters of the network resilience mechanisms. On the other hand, a correlation between the QoD and QoE characteristics gives an input to the resilience solutions for an adequate and reliable provision of the service.

It is obvious that the both parts should operate jointly and a quality (in a broad sense) plays an important role here. Moreover, the interrelation between the QoS, QoD and QoP characteristics and the QoE metrics could help us to create novel solutions for a higher resilience of the networks or systems in the case of disruptions. Broadly speaking, the interrelation between the different quality aspects could help us, for instance, in:

- forecasting the upcoming disruptions of the telecommunication network;
- alerting a service performance degradation;
- protecting a service data with a higher priority;
- re-routing of data;
- re-configuration of a network topology.

3 Vulnerability of Wireless Systems to Different Environmental Conditions

TBD: short intro into subsections here

3.1 Free Space Optical Communication System

Free Space Optical (FSO) communication is developed as a solution for the always increasing requirements for reliable and high speed wireless data transmission. Nevertheless, the system vulnerability to various tropospheric weather conditions leads to imposing restrictions in terms of induced atmospheric fading as well as attenuation. These factors can significantly decrease the QoS parameters (Bit Error Rate (BER), Signal to Noise Ratio (SNR), *etc.*) and consequently to trigger various issues during FSO system operation. To prevent the harsh consequences of the tropospheric conditions influencing the wireless optical communication link a few mitigation techniques are developed. These include adoptive optics technology, different coding and modulations as well as multiple transmitters and receivers solution. The enhancement of these techniques is fully dependent on the fundamentals behind the atmospheric effects influencing the transmitted optical beam.

Decreased availability of FSO communication systems is mainly due to atmospheric impairments including scattering and absorption as well as turbulence induced fading. In particular, the scattering is predominantly caused by water particles with radii comparable to the wavelength of a typical optical carrier operating in near infrared domain. Depending on the size of the water droplets there are two main scattering regimes namely non-selective (geometrical) as well as Mie scattering. The attenuation due to Rayleigh scattering is negligible and it is not considered.

The effect of fog (clouds) contains particles with radii nearly identical to the applied wavelength, which leads to Mie scattering with an attenuation of up to 300 - 350 dB/km. Due to the high complexity of the analytical approach, several empirical models for calculation of the Mie scattering attenuation are proposed. The most prominent include Kim, Kruse and Al Naboulsi models, which are shown in Fig. 3. The attenuation [dB] versus visibility is examined in terms 850 nm FSO wavelength. The accepted visibility threshold is 2 % [21].

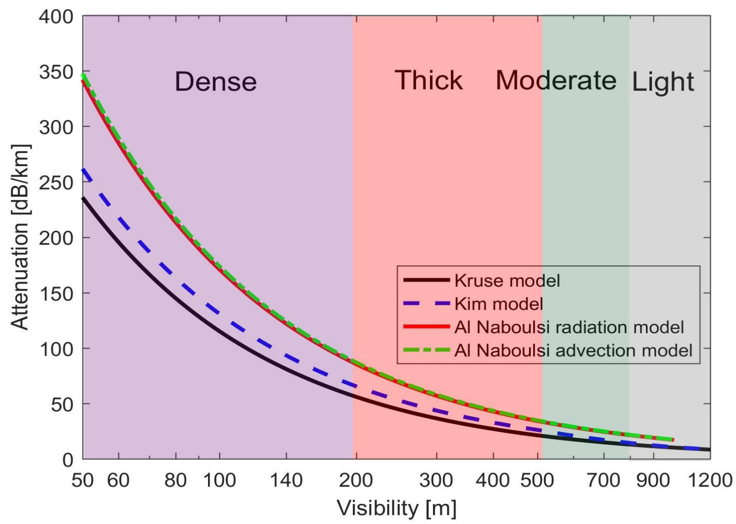

Fig. 3 Fog attention versus visibility in terms of three different empirical fog models

Despite the small differences, all three fog models have similar behavior. The Kruse model is mainly developed in terms of dense haze and its precision for fog with visibility <1 km is low. To address this issue, Kim and Al Naboulsi empirical models are considered. In particular, Al Naboulsi is valid for wavelength range between 0.69 - 1.55 Âţm and it provides separate equations for maritime and continental fog. The disadvantage of this model is the 1 km upper bound on the visibility parameter.

In addition to fog effect, the atmospheric influences of snow and rain should be taken into account. Due to the larger particlesâĂŹ radii, both of them are classified as non-selective geometrical scattering. The rain is measured in [mm] per hour scale and its normal range is between 1 mm/h for light and 100 mm/h for heavy rain. Based on a well-proved empirical rain model, the attenuation [dB] versus [mm/h] is shown in Fig. 4. In comparison with Mie scattering, the maximum rain attenuation reaches up to 25 dB/km [22].

Along with rain, the non-selective scattering due to snow is also of high importance. In general, snow could be measured based on snowfall depth or melted snow scale in [mm] per hour. In the current study, similar to fog, a visibility scale in [m]

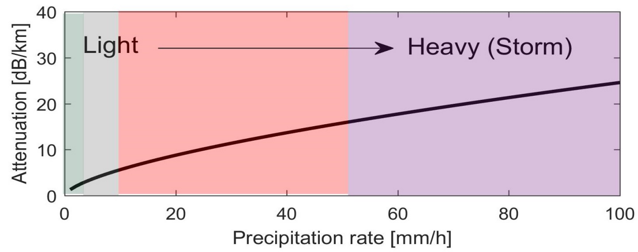

Fig. 4 Rain attention versus precipitation rate

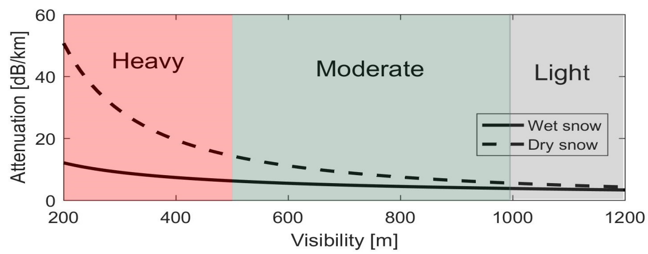

Fig. 5 Snow attention versus visibility for two different snow types

is used, which is derived based on the following expression: Visibility [m] = 1000 / Rate [mm/h]. In general, the range is between 1 âĂŞ 5 mm/h which corresponds to 1000 - 200 m visibility. The attenuation strongly depends on the humidity parameter (see Fig. 5). For dry snow, the attenuation could reach up 50 dB/km while the maximum attenuation in the case of wet snow does not exceed 20 dB/km [22].

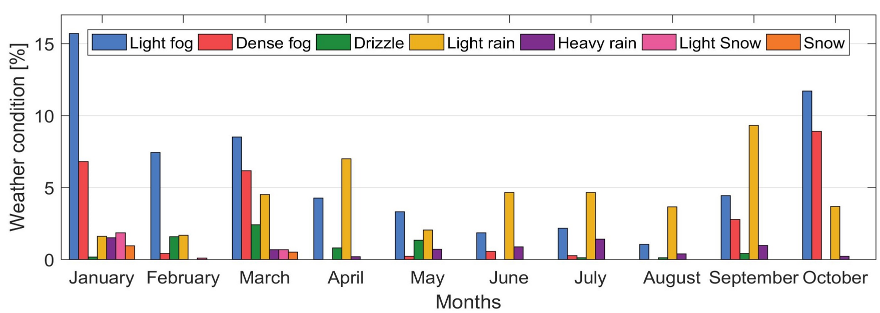

Fig. 6 10 months atmospheric measurement campaign in Graz, Austria

In the presence of light and moderate atmospheric weather conditions, the main FSO system impairments are caused due to Mie scattering. The results based on a 10 months measurement campaign, carried out in Graz, Austria, are provided in figure 6 [23]. According to the graph, the fog and light rain atmospheric effects prevail during the measurement period. However, the attenuation due to light rain is minimal (see Fig. 4). Consequently, the induced weather-based disruptions are due to Mie scattering (continental fog).

3.2 Wireless Sensor Network

Wireless Sensor Networks (WSN) are widely used for implementation of Internet of Things (IoT) concept solving one of the main challenges by providing a reliable IoT architecture. The data transmitting joint data transferring concept by an alerting a service performance degradation in different weather conditions have been tested in this chapter. Many wireless sensor networks operating outdoors are exposed to changing weather conditions, which may cause severe degradation in a system performance. The main impact on performance is assessed by Quality Quality of Delivery (QoD) parameters. QoD can be characterized by different indicators, e.g: error recovery procedures, packet loss, retransmission process, data processing, flow control, integrity of data (as it is described in the first subchapter). 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). In [24] the quality and reliability of WSN network was

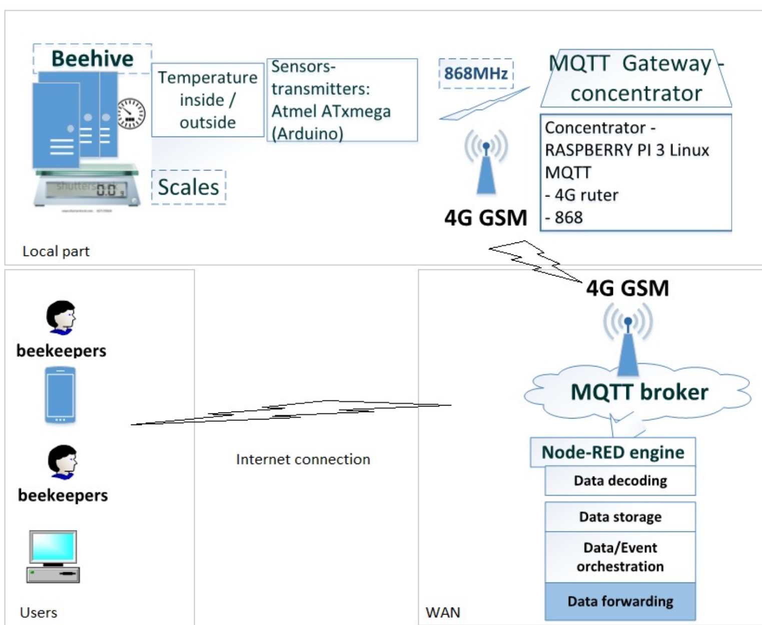

Fig. 7 Test bed layout: beehive monitoring system

tested using bee hives monitoring system. Bee colony is considered as one of the most complex social systems in the world of insects. In the project Autonomous beekeeping, the Riga Technical University has created a unique autonomous beekeeping technology, based on IoT approach, used to monitor bee gardens remotely. The purpose of or research is to test the individual elements of the Autonomous Beekeeping system in field conditions, including WSN performance, in one of the bee hives.

Fig. 8 Example of the installation of beekeeping system.

Figure 7 shows the test organization scheme. The highly reliable and secure LTE router with I/O, GNSS and RS232/RS485 for professional applications was used. Router delivers high performance, mission-critical cellular communication and GPS location capabilities. RUT955 is equipped with connectivity redundancy through dual SIM failover. External LTE omnidirectional antenna connectors make it possible to attach desired antennas and to easily find the best signal location. There are 3 sensors - transmitters to measure the temperature inside of the hive in different locations (in the centre and sides), and one sensor outside the beehive to get the outdoor air temperature (Fig. 8). The weight of each hive is measured online by specially designed weight platform depicted in. The unit periodically reads the data from the platform sensor and transmits them to a gateway - concentrator without data processing. The data processing is performed by a concentrator. Radio chip semtech sx1231H and SMA antenna s used. Data encrypted using standard AES-128. The temperature transmitters transfer data to the server every 15 minutes, the weight sensor transmits data to the server every 5 minutes. All data collected on the server are displayed in a graphical form. The measurements are received by broadcast from sensor ISM range signal. For example, the weight sensor 1C3003AE0030 transmitted data via radio signal using ISM 868MHz diapason. The users - beekeepers interprets these data manually, using graphics, based on his own experience and understanding of ongoing processes in the hive. The measurement accuracy and

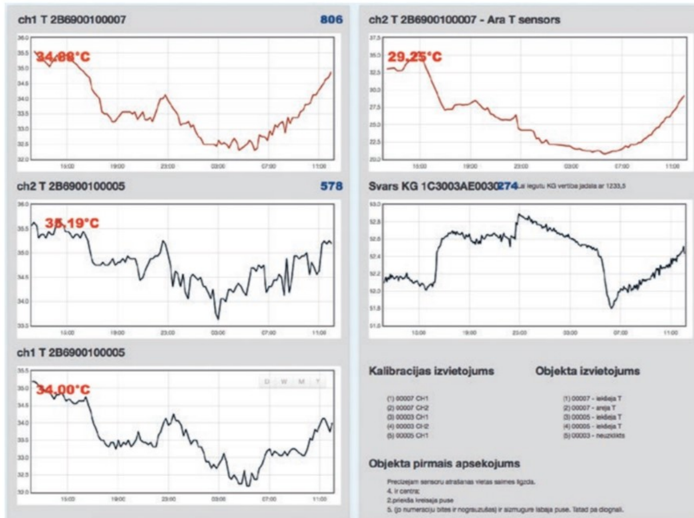

Fig. 9 Web based interface of on-line published monitoring results

data quality from the testing network are in line with the initial forecasts. It is no doubts that the nearly on line reading of the weight, temperature and humidity data opens new opportunities to beekeepers for analysing and planning ongoing actions at a more detailed level, than it was originally anticipated. The weather impact on the tested system was assessed, using RSSI data and external data from the Weather monitoring system in Botanical garden in Riga. Environment factor and RSSI Correlation during the summer period is presented in the Figure 10. The weather impact,

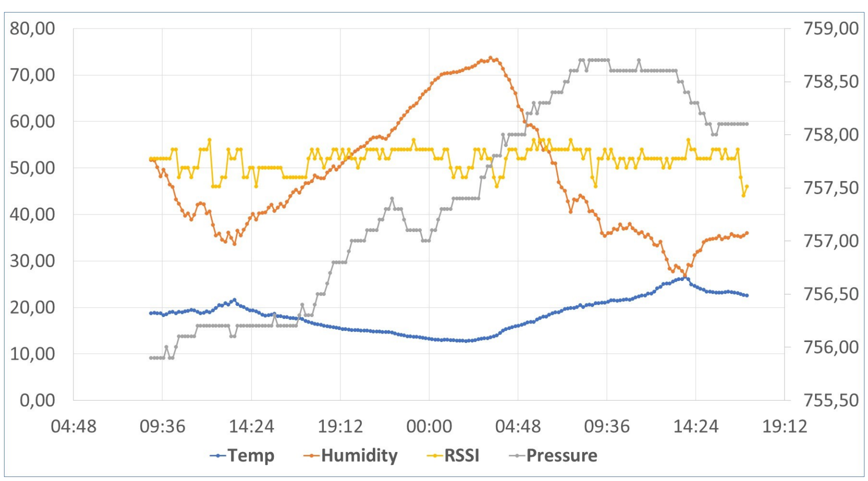

Fig. 10 The RSSI dependence from weather parameters during summer reference period

measured during summer period is a reference for evaluation of the Quality of Delivery (QoD). The temperature data at the center of the beehive confirms that the bees maintain a constant ecosystem within +/- 0.5 °C. The measured temperature absolute mean value of 34.8 °C appeared to be higher in comparison to assumption. TBD: include experimental results for winter conditions

3.3 Modular Positioning System

Modular positioning system is based on assumption, that various technologies used for position estimation provide optimal solution under different signal propagation conditions and in different environments. Therefore, modular positioning system was proposed to provide seamless positioning in heterogeneous environment. The system is designed in a way that it will automatically switch between available technologies based on qualitative parameters of the measured signals. GNSS (Global Navigation Satellite Systems) positioning services are widely available in the outdoor environments.

However, indoor environment or areas close to the buildings have to be covered by other localization approaches. So far, positioning based on Wi-Fi or cellular technologies seems to be optimal solution, since these technologies are ubiquitously available in populated areas. Fingerprinting approach is most widely used. With this approach, positions of transmitters do not need to be known, thus it is possible to utilize signals from existing infrastructure. On the other hand, fingerprinting positioning approach require calibration measurements at known positions that are used to create a radio map. Position of mobile device can then be estimated based on a comparison of actual RSS measurements with the radio map.

However, positioning accuracy depends on quality of the radio map, hence any environmental changes that affect a propagation of radio signal will negatively affect a performance of the positioning system. Therefore, it is important to evaluate how environmental changes could possibly impact Received Signal Strength (RSS) measurements for different technologies utilized by positioning system. Since, errors of RSS measurements have a negative impact on accuracy of position estimates, thus reduce Quality of Service (QoS) when it comes to localization service.

A. Impact of environment on Wi-Fi signals

Wi-Fi signals are widely used for indoor positioning thanks to their availability. RSS measurements are available on a wide range of devices, therefore deployment of localization service is relatively easy. Heterogeneity of Wi-Fi enabled devices, caused by different antenna designs, chip-sets or software equipment, can cause positioning errors [25]. However, these problems can be suppressed by calibration approaches that have been described recently in [26].

On the other hand it is much harder to tackle with environmental changes that affect propagation of the radio signal in the environment. These can be caused by differences in number of moving obstacles (users, people, cars in outdoor environment, etc.), differences in furniture placement or by some renovations happening in buildings. Another source of the difference in propagation conditions might be caused by changes of weather.

Wi-Fi signals are transmitted in two frequency bands - 2.4 GHz band and 5 GHz band. The 2.4 GHz band is more widely used in indoor environment, while 5 GHz Wi-Fi is more successful in the outdoor spaces. However, both of the signals can be used for positioning purposes in both indoor and outdoor environments.

There is already a large number of studies performed to evaluate impact of weather on 2.4 GHz Wi-Fi links. Study presented in [24] claims there is a correlation between weather conditions and changes of RSS values on radio links at 2.4GHz frequency band. However, these changes are relatively small with highest fluctuation of Âś2dB. Authors in [27] conclude that there is correlation between temperature and humidity and RSS fluctuations in the indoor environment. Authors claimed that there is a linear relationship of both parameters and change of RSS values. Nonetheless, differences between RSS values are quite small and there is no information about number of people and other moving objects presented in the area during the measurement campaign.

On contrary, results for long distance link on 2.4GHz Wi-Fi presented in [28] claim that even heavy rain caused only very small changes in RSS value, while such changes appeared even during clear weather.

We have performed measurements over the course of one week to analyse impact of environmental changes on RSS of Wi-Fi signal. The measurements were done in the office environment at the Department of Multimedia and Information-Communication Technology at the University of Zilina, during the semester, so there was relatively large variation of people moving in the area during the day. During the measurements weather conditions in the outdoors have changed significantly including rainy, clear and foggy conditions. Anyhow, their impact on RSS measurement is not significant as can be seen from the Figure 11. It can also be seen that the highest RSS fluctuations were detected during working days between 6AM and 6PM. These are caused by movement of people in the area. It can also be seen that RSS can fluctuate significantly even when building is completely empty (during night or during weekend). These fluctuations can be up to Âś3dB even when area is empty and there are no moving objects.

On top of indoor measurements, we have performed tests in outdoor environment to evaluate impact of different weather conditions on a performance of positioning system based on Wi-Fi signals in 5 GHz band. Since Wi-Fi operating in 5 GHz band is widely deployed in outdoor areas, it might be more significantly affected by weather conditions, which could result in decreased performance of the positioning system. Localization errors achieved during tests performed in various environmental conditions are presented in Table 1.

Based on the results achieved under different weather conditions we can conclude that weather does not have a significant effect on the performance of the positioning

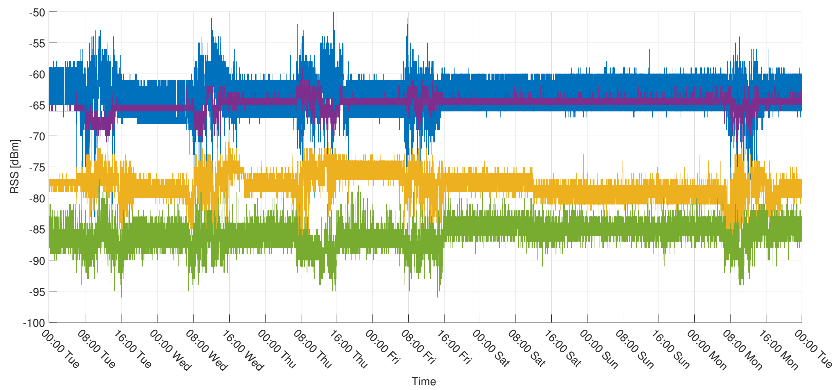

Fig. 11 RSS dependence on environmental conditions

Table 1 Dependence of localization error in 5GHz Wi-Fi on environmental conditions

Radio map		**Localization**		**mean [m]**	**median [m]**	**std [m]**
pedestrians	**weather**	**pedestrians**	**weather**			
low	clear	low	clear	12.3	9.6	9.9
low	clear	high	clear	28.5	15.9	37.9
very low	snow	very low	snow	9.9	5.3	11.6
very low	snow	high	clear	26.3	14.5	31.3
high	clear	high	clear	20.2	9.2	28.5
high	clear	very low	rain	19.4	11.5	21.4

system. Moreover, it can be concluded, that the impact of the moving objects in the area is more significant and can have a negative impact on the performance of the system.

B. Impact of environment on GSM signals

Similarly to Wi-Fi signals, GSM signals can also be used to estimate a position of mobile devices in the heterogeneous environments. However, from the experiments it is clear that GSM signals provide lower positioning accuracy [29]. This is due to the fact that GSM signal use lower frequency band and therefore attenuation on the same distance is less significant compared to Wi-Fi, thus difference between reference measurements is smaller. Unfortunately, in some cases Wi-Fi signals are not present, accordingly GSM can be used as a back-up solution, since a coverage of GSM cellular network is close to 100%.

In contrast to Wi-Fi, GSM transmitters are in general covering much larger area and are placed further from users, therefore, changes in weather could possibly have higher impact on RSS fluctuations. To analyze RSS fluctuations due to different weather conditions, we have used measurements from AmbiLoc database [30], which includes GSM data in 900MHz frequency band measured in different days and times at fixed positions. The database also include data from nearby meteorological station, hence it is possible to compare RSS measured under different weather conditions.

Table 2 Dependence of RSS difference on environmental conditions

conditions	mean (dBm)	min (dBm)	max (dBm)
clear (summer)	1.64	0.05	4.7
clear (winter)	1.99	0.02	9.7
fog	2.05	0.03	5.5
rain	2.43	0.01	7.1

From Table 2 it can be seen that an impact of different weather conditions have minimum effect on GSM signals. The data presented in the table are based on measurements performed during one year period at the same locations. A set of data measured at the same position under different conditions was extracted from the AmbiLoc database [30]. Measurements performed during summer period and clear conditions were used as a reference, since these should be the least affected values by environment conditions. Measurements performed under the same conditions have reached the best mean value of RSS difference. This might be caused by the fact that during summer period the area was quite empty, since measurements were performed at the campus of a university.

On the other hand, the worst mean value of the RSS difference was achieved under rainy conditions, however, it is important to note that these measurements were performed with some people moving around in the area. The values are based on a comparison of RSS signals at 43 frequency channels measured in the area. We can conclude that difference of mean RSS values between two most extreme cases is less than 1 dB and can be considered statistically insignificant.

TBD: short summary from section 3 here

4 Quality-driven Techniques to Improve Resilience

TBD: short intro into subsections here

4.1 Alert to React and Prevent Service Performance Degradation in FSO communication

It is already clear, that the network resilience describes the ability of the network to provide and maintain an **acceptable level of service** in the face of various disruptions to a normal operation. When one or more parameters of the required quality of service performance fall down under the predetermined values, it results in a beginning of a service performance degradation. Also, it results in a lower service quality, perceived by the users. Based on the results coming from the experimental studies done at the TU Graz, it was concluded that the communication over FSO network is very sensitive to different weather conditions (see 3.1 for more detail). In this context, a process of service performance degradation starts under an influence of the different weather conditions and get worse when a level of the degradation intensifies. In this specific period of time the service is still perceived as available but with a limited quality perceived by the end user. An initial reaction of the provider is based on the service disruption impact on the end users. This means that a start of the disruption caused by various weather conditions can be determined using certain parameters of Quality Experience, which basically is used to describe how users are satisfied with the provided service quality.

The proposed technique for an alert (Fig. 12) is based on an idea, that the ser-

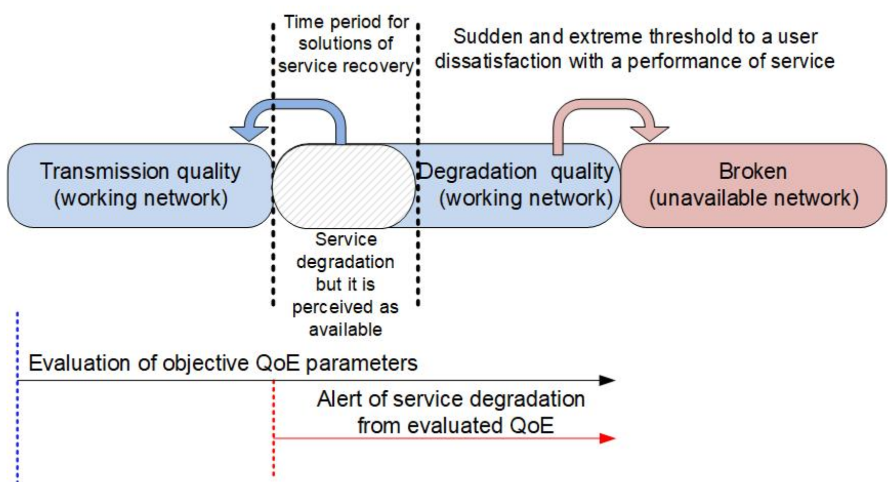

Fig. 12 Technique for an alert

vice, which is provided to the end user during a time period of service degradation can be equated as an acceptable level of a service. In this case, the continuous evaluation of the objective QoE parameters from the provider's point of view could help to identify the beginning of the weather-induced disruption of the transmission and prevent service suspension by activating proper resilient mechanisms over the network. The authors have found that one of the weather conditions, i.e. a fog, is the most serious factor of service performance degradation when it comes to the FSO. So, the proposed technique is focused on it.

The experiments dealing with the fog influence on the service performance over FSO have shown, that intense fog strongly impacts the propagation of wireless signal while increasing the attenuation of it ,and in contrast, decreasing service QoS parameters (BER, SNR) and a visibility for the wireless communication over the link. Thus, an objective assessment of the perceptual service quality should consist not only of the main QoE metrics, but also of their correlations with the QoS parameters and the external factors. In this case, the objective QoE evaluation depends on values of BER, SNR and visibility. Figure 13 shows a dependence of the evaluated objective Quality of Experience on QoS parameters and visibility for service performance over FSO network. The evaluated objective QoE is divided into

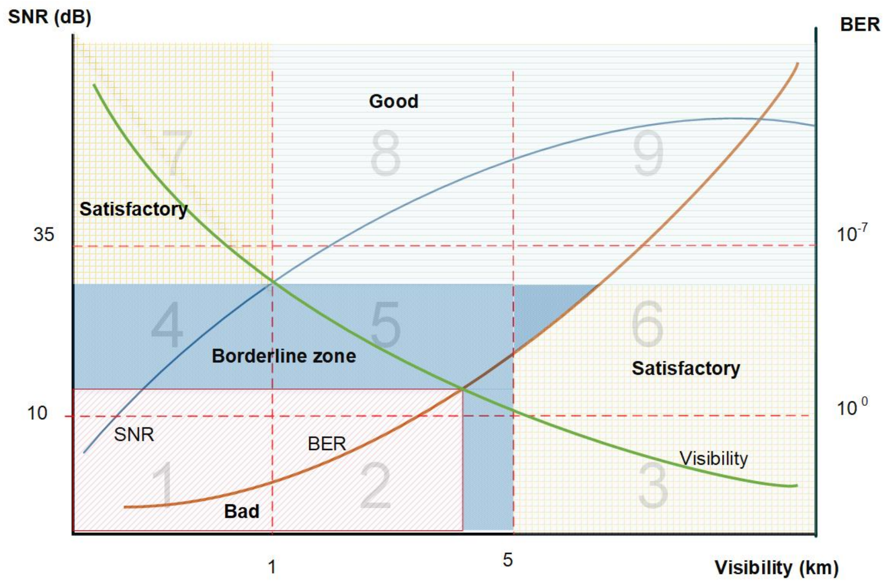

Fig. 13 Objective QoE dependence on QoS parameters and visibility

9 zones, which indicate a perceptual quality of a service that the end user can expect/experience in a presence of the specific values of the BER, SNR and visibility (Table 3).

Table 3 Values of BER, SNR and visibility in QoE zones

Zones	SNR(dB)	BER	Visibility (km)
1st zone (bad quality)	< 12	$> 10^0$	~ 1
2nd zone (bad quality)	< 12	$\sim 10^0$	~ 4
3rd zone (satisfactory quality)	< 12	$\sim 10^0$	> 4
4th zone (poor quality)	$12 \div 30$	$10^0 \div 10^{-3}$	~ 1
5th zone (poor quality)	$25 \div 35$	$10^{-3} \div 10^{-5}$	~ 4
6th zone (satisfactory quality)	> 35	$10^{-5} \div 10^{-7}$	> 4
7th zone (satisfactory quality)	> 35	$\sim 10^{-7}$	~ 1
8th zone (good quality)	> 35	$< 10^{-7}$	~ 4
9th zone (excellent quality)	> 35	$< 10^{-7}$	> 4

It can be seen from Fig. 14, that if BER is between 10^0 and 10^{-5} while SNR goes from 12 to 35 dB and the visibility is less than 4 km (Table 3), the service will be provided in a poor quality, which means that a process of a degradation of a service has already started. In this case, the 3rd and 4th zones should be considered as a

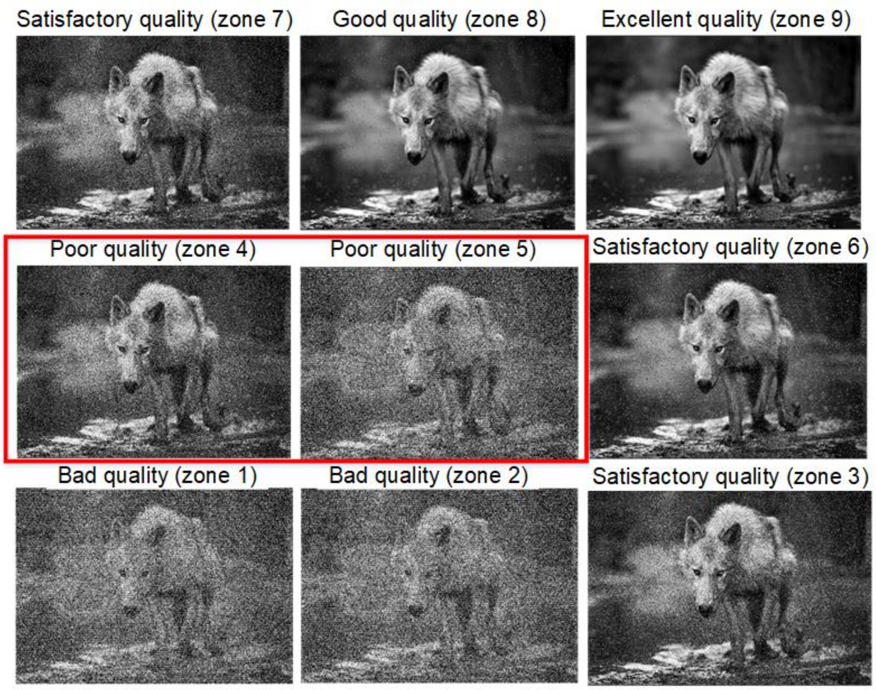

Fig. 14 Evaluated Objective QoE in each zone

borderline area, in which the degradation of a service has started, but the service is still considered acceptable. It is worth to noting here, that from this area there are just two options for a service provision, i.e. to start a recovery process of service transmission, or wait until the network will be broken and service will stop.

4.2 Rerouting Mechanism in WSN

The network reliability is critical for assurance of autonomous beekeeping system stability, that's why the detection of battery drain in in-field monitoring systems is crucial. As it has been shown in chapter 3.2, the transmission system performance degradation can be caused by battery drain due to extreme temperature. We believe, that an impact on Quality of Service (QoS) parameter, i.e. battery energy, could be mitigated by rerouting of data in WSN. Therefore, this section is aimed on proving this assumption.

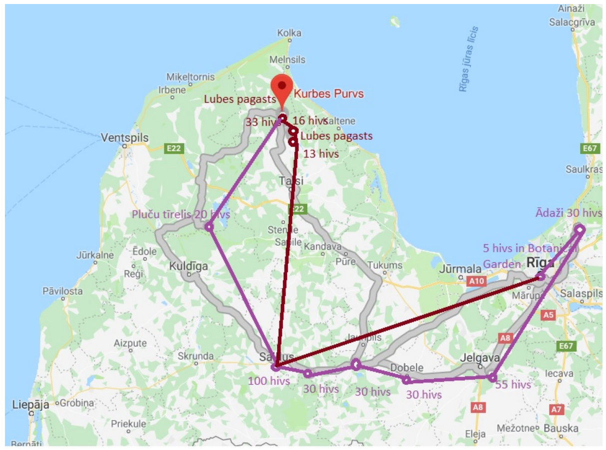

Fig. 15 Distribution of WSN nodes, according to the placement of beehives during the season period

The modelling of network rerouting is based on the "Autonomous Beekeeping" network structure on the Fig. 15. The second generation of network will be developed, based on the existing geographical location of bee hives. The network topology is dynamic due to dynamic nature of the beekeeping business. WSN power outages rise a need to reroute data in WSN, according to the actual parameters of the network in order to assure defined level of signal transmission in accordance to Quality of Service (QoS) requirements. The methodology of route recalculation is based on the level of LQE (Link Quality Evaluation) (Eq. 2). LQE assure the best topology configuration in the certain moment of the transmission, according to the parameters, which may impact WSN network reliability. The sum of the coefficient (Eq. 2) for impact to the parameters should be equal to 1:α_1 + α_2 + ... + α_n =1.

$$Route_j = min/max(LQE), j \in neighbor \tag{1}$$

$$LQE = \alpha_1 (\frac{RSSI_i}{RSSI_{min}}) + \alpha_2 (1 - \frac{P_i}{P_{max}}) \tag{2}$$

$$RSSI \to f(d, Psensor) \tag{3}$$

The rerouting condition is described by minimum or maximum (depending on the physical meaning of the coefficients alpha) of the Link Quality Evaluation parameter LQE (Eq. 1), the route for certain time moment depends on the RSSI, Signal to noise ratio (SNR) or other relevant quality parameters, according to the specific configuration of the given WSN. RSSI depends on distances between the nodes / sensors and energy/power/signal strength level of the sensor battery *Psensor* (Eq. 3).

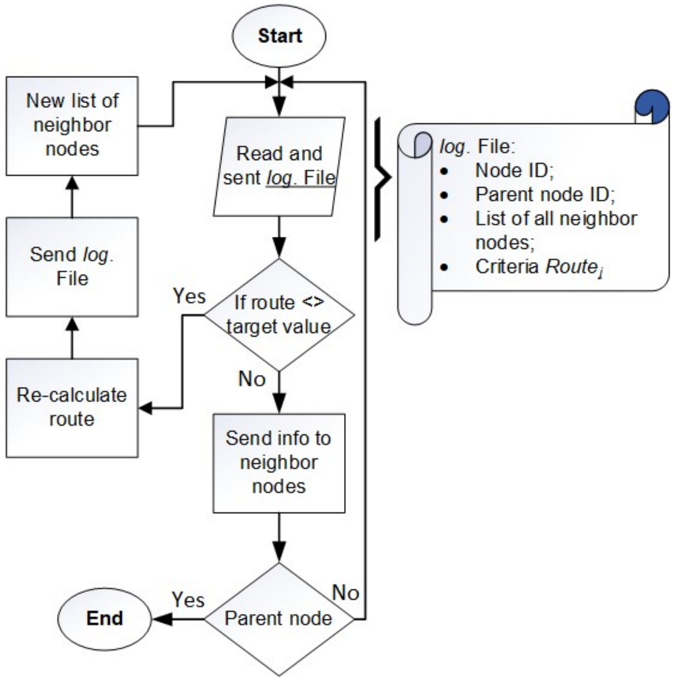

Fig. 16 Re-configuration Algorithm of a Network Topology, according to the LQE and WSN rerouting Mechanisms

The algorithm will perform rerouting in WSN network according to the LQE. WSN

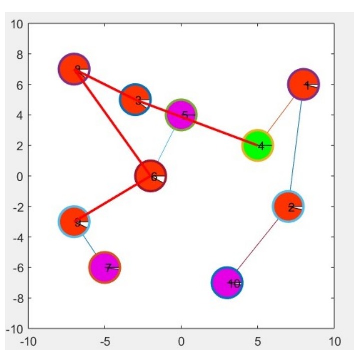

Fig. 17 WSN with a main routing

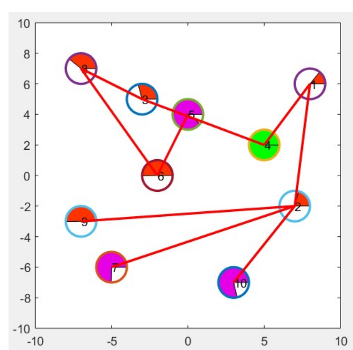

Fig. 18 Rerouting of WSN

rerouting mechanisms (Fig. 17, 18) may be used in both LQE min or max cases. The actual topology of WSN is defined by the energy level of the node due to temperature conditions, distances between sensor nodes.

4.3 Adaptation of localization system

As it was shown in 3.3 changes in environment caused by movement of obstacles can have negative impact on RSS readings and thus can reduce Quality of Service, e.g. accuracy, provided by positioning system. Recently, method based on regression was proposed to estimate positioning accuracy in fingerprinting based positioning [31]. Although, it requires large amount of data for training and its application in new areas might require collection of data and new fitting of the model.

Possible way to overcome lack of tools to detect localization errors caused by changes in the environment might be to use data from other sensors available in widely used mobile devices i.e. magnetometers, gyroscopes, accelerometers , etc. These sensors can provide additional information on movement of the user, therefore it might be possible to detect large localization errors of fingerprinting algorithm. On top of that, data from the sensors are available all the time, therefore, implementation of this solution would provide localization service even in areas with poor coverage of the signals and thus improve QoS by improving availability of the system. We foresee that modification of the system, as can be seen on 19, will make it possible to perform adaptation of the system to changed environmental conditions. In the figure blocks for data fusion and adaptation are added to the system architecture. Modified system will estimate position using RSS measurements and fingerprinting, similarly to modular positioning system described in 3.3. Moreover, second position estimate will be based on data from Inertial Measurement Unit (IMU) and Pedestrian Dead Reckoning (PDR) algorithm.

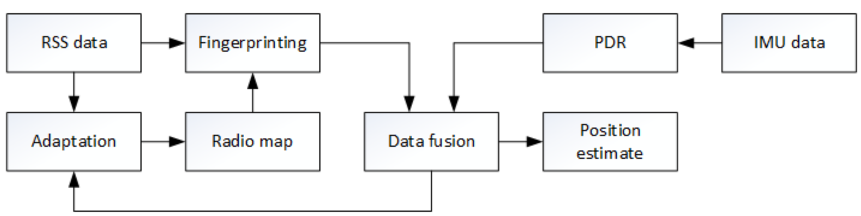

Fig. 19 Modification of the localization system

The data fusion block will be responsible for fusion of position estimates and will help to detect localization errors caused by increased fluctuations in RSS readings due to environmental changes. The second newly added block, Adaptation, will analyse data from data fusion and RSS measurements and will perform update of the radio map if necessary.

The Adaptation block will have to make decision if fluctuations are caused only by increased movement of people in the area, or by some permanent changes in environment, i.e. replacement of furniture, renovation works, etc. Based on this classification it can decide to update radio map using measured RSS values and thus reduce positioning error of the fingerprinting localization system. It is important to note that algorithm will have to use data from different users measured in locations with higher RSS fluctuations over longer period of time in order to perform classification and successful radio map updates.

Moreover, the Adaptation block could be used to extend radio map in case that users will move out of the area that is currently covered by the localization system. This will be possible thanks to the fact that PDR is able to estimate position of user based on previous position and IMU data. This position can be linked to RSS measurements and stored in the radio map as additional reference point.

5 Conclusions

TBD: later

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References

1. E. K. Çetinkaya and J. P. Sterbenz, "A taxonomy of network challenges," in *2013 9th International Conference on the Design of Reliable Communication Networks (DRCN)*, pp. 322–330, IEEE, 2013.
2. A. Mauthe, D. Hutchison, E. K. Cetinkaya, I. Ganchev, J. Rak, J. P. Sterbenz, M. Gunkelk, P. Smith, and T. Gomes, "Disaster-resilient communication networks: Principles and best practices," in *2016 8th International Workshop on Resilient Networks Design and Modeling (RNDM)*, pp. 1–10, IEEE, 2016.
3. R. Bruzgiene, L. Narbutaite, E. Leitgeb, P. Pezzei, and T. Plank, "The effect of weather on quality of experience in optical wireless communication system (selected from cemaâĂŹ17 conference)," *Journal of Applied Electromagnetism*, vol. 19, no. 2, 2017.
4. R. Marfievici, A. L. Murphy, G. P. Picco, F. Ossi, and F. Cagnacci, "How environmental factors impact outdoor wireless sensor networks: a case study," in *2013 IEEE 10th international conference on mobile ad-hoc and sensor systems*, pp. 565–573, IEEE, 2013.
5. C. A. Boano, M. Zúñiga, J. Brown, U. Roedig, C. Keppitiyagama, and K. Römer, "Templab: A testbed infrastructure to study the impact of temperature on wireless sensor networks," in *Proceedings of the 13th international symposium on Information processing in sensor networks*, pp. 95–106, IEEE Press, 2014.
6. F. Yaghoubi, J. Chen, A. Rostami, and L. Wosinska, "Mitigation of rain impact on microwave backhaul networks," in *2016 IEEE International Conference on Communications Workshops (ICC)*, pp. 134–139, IEEE, 2016.
7. M. Tornatore, J. André, P. Babarczi, T. Braun, E. Følstad, P. Heegaard, A. Hmaity, M. Furdek, L. Jorge, W. Kmiecik, *et al.*, "A survey on network resiliency methodologies against weather-based disruptions," in *2016 8th International Workshop on Resilient Networks Design and Modeling (RNDM)*, pp. 23–34, IEEE, 2016.

8. J. Rak, “Design of weather disruption-tolerant wireless mesh networks,” in *2012 15th International Telecommunications Network Strategy and Planning Symposium (NETWORKS)*, pp. 1–6, IEEE, 2012.
9. I. M. Rafiqul, M. M. Alam, A. K. Lwas, and S. Y. Mohamad, “Rain rate distributions for microwave link design based on long term measurement in malaysia,” 2018.
10. J. Rozhon, P. Blaha, M. Voznak, and J. Skapa, “The weather impact on speech quality in gsm networks,” in *Computer Networks* (A. Kwiecień, P. Gaj, and P. Stera, eds.), (Berlin, Heidelberg), pp. 360–369, Springer Berlin Heidelberg, 2012.
11. A. Dhekne, M. Gowda, R. R. Choudhury, and S. Nelakuditi, “If wifi aps could move: A measurement study,” *IEEE Transactions on Mobile Computing*, vol. 17, pp. 2293–2306, Oct 2018.
12. P. Brida and J. Machaj, “Impact of weather conditions on fingerprinting localization based on ieee 802.11a,” in *Computational Collective Intelligence* (M. Núñez, N. T. Nguyen, D. Camacho, and B. Trawiński, eds.), (Cham), pp. 316–325, Springer International Publishing, 2015.
13. M. Katz, M. Matinmikko-Blue, and M. Latva-Aho, “6genesis flagship program: Building the bridges towards 6g-enabled wireless smart society and ecosystem,” in *2018 IEEE 10th Latin-American Conference on Communications (LATINCOM)*, pp. 1–9, IEEE, 2018.
14. ISO Central Secretary, “Information technology – open systems interconnection – basic reference model: The basic model,” Standard ISO/IEC 7498-1:1994, International Organization for Standardization, Geneva, CH, 2000.
15. M. Kayri and İ. Kayri, “A proposed" osi based" network troubles identification model,” *arXiv preprint arXiv:1009.6045*, 2010.
16. ITU-T, “Definitions of terms related to quality of service,” Recommendation E.800, International Telecommunication Union, Geneva, 2008.
17. ITU-T, “Vocabulary for performance, quality of service and quality of experience,” Recommendation P.10/G.100, International Telecommunication Union, Geneva, Nov. 2017.
18. T. N. Minhas and M. Fiedler, “Quality of experience hourglass model,” in *Computing, Management and Telecommunications (ComManTel), 2013 International Conference on*, pp. 87–92, IEEE, 2013.
19. A. Kumar and Y. Sun, “Quality-of-protection (qop): A quantitative methodology to grade security services,” in *2008 28th International Conference on Distributed Computing Systems Workshops (ICDCS Workshops)(ICDCSW)*, vol. 00, pp. 394–399, 06 2008.
20. J. Tapolcai, P. Cholda, T. Cinkler, K. Wajda, A. Jajszczyk, A. Autenrieth, S. Bodamer, D. Colle, G. Ferraris, H. Lonsethagen, *et al.*, “Quality of resilience (qor): Nobel approach to the multi-service resilience characterization,” in *Broadband Networks, 2005. BroadNets 2005. 2nd International Conference on*, pp. 1328–1337, IEEE, 2005.
21. S. Muhammad, B. Flecke, E. Leitgeb, and M. Gebhart, “Characterization of fog attenuation in terrestrial free space optical links,” *Optical Engineering*, vol. 46, no. 6, 2007.
22. S. Muhammad, P. KÃűhldorfer, and E. Leitgeb, “Channel modeling for terrestrial free space optical links,” in *Proceedings of 2005 7th International Conference Transparent Optical Networks (ICTON 2005)*, IEEE, 2005.
23. E. Leitgeb, M. Gebhart, P. Fasser, J. Bregenzer, and J. Tanczos, “Impact of atmospheric effects in free space optics transmission systems,” in *Proceedings of SPIE - The International Society for Optical Engineering, Atmospheric Propagation*, SPIE, 2003.
24. J. Luomala and I. Hakala, “Effects of temperature and humidity on radio signal strength in outdoor wireless sensor networks,” in *Computer Science and Information Systems (FedCSIS), 2015 Federated Conference on*, pp. 1247–1255, IEEE, 2015.
25. C. Laoudias, R. PichÃľ, and C. G. Panayiotou, “Device signal strength self-calibration using histograms,” in *2012 International Conference on Indoor Positioning and Indoor Navigation (IPIN)*, pp. 1–8, Nov 2012.
26. J. Machaj and P. Brida, “Survey of device calibration techniques for fingerprinting localization algorithms,” *Communications*, vol. 15, no. 4, pp. 48–53, 2013.
27. A. Guidara, G. Fersi, F. Derbel, and M. B. Jemaa, “Impacts of temperature and humidity variations on rssi in indoor wireless sensor networks,” *Procedia Computer Science*, vol. 126, pp. 1072–1081, 2018.

28. M. Rademacher, M. Kessel, and K. Jonas, "Experimental results for the propagation of outdoor ieee802. 11 links," *VDE ITG-Fachbericht Mobilkommunikation*, vol. 22, 2016.
29. M. Mlynka, P. Brida, and J. Machaj, "Modular localization system for intelligent transport," in *Recent Developments in Computational Collective Intelligence*, pp. 115–124, Springer, 2014.
30. A. Popleteev, "Ambiloc: A year-long dataset of fm, tv and gsm fingerprints for ambient indoor localization," in *8th International Conference on Indoor Positioning and Indoor Navigation (IPIN-2017)*, 2017.
31. F. Lemic, V. Handziski, M. Aernouts, T. Janssen, R. Berkvens, A. Wolisz, and J. Famaey, "Regression-based estimation of individual errors in fingerprinting localization," *IEEE Access*, vol. 7, pp. 33652–33664, 2019.