Short Term Scientific Mission (STSM) Final Report on topic

RESILIENCE OF OPTICAL WIRELESS TELECOMMUNICATION SYSTEM ON THE WEATHER-BASED DISRUPTIONS

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Working group: WG2 - Weather-based disruptions

1. Purpose of this STSM

Optical Wireless telecommunication systems are becoming more and more popular for delivering high-speed broadband traffic. The way optical wireless transceivers operate is more or less the same as fiber optics ones; however, since laser signals are transferred through the atmosphere, the path loss between the transmitter and the receiver is getting raised due to a various external factor that appears on weather. Resilience of such systems against fast-time-changing disruptions is dependent to different weather conditions (fog, snow, haze, rain and etc.)

The overall goal of this STSM was to investigate in detail the influence of different weather conditions on the link of Optical Wireless system and to identify the possible techniques to increase the resilience of such system against the weather-based disruptions.

The main objectives are:

- to get familiar with Optical Wireless (OW) systems and to analyse different weather conditions affect to the vulnerability of OW links;
- to perform the investigations on several OW transmission systems considering the behavior of OW links in presence of different weather conditions;
- to identify the ways to improve the OW receiver and transmitter technologies considering it impact to increase the resilience of Optical Wireless systems;
- to analyze and summarize the results of STSM for joint publications.

The output of this work provides some key insights into the behavior of OW link on different weather conditions and will be used for further investigations within the objectives in RECODIS WG2 group.

2. Description of the work carried out during the STSM

During the whole stay in Graz and work in Institute of Microwave and Photonic Engineering of Graz University of Technology, it was done:

- *regular meetings* with the researches from the Institute of Microwave and Photonic Engineering by discussing their achievements by investigating Optical Wireless communication systems and it resilience on the weather-based disruptions;
- the *STSM grantee’s presentations*:

  a) about her university, the faculty of Electrical and Electronics engineering and Department of Telecommunications, study possibilities for foreign students, laboratories in the Department of Telecommunications and grantee’s research areas;

  b) about her research within COST action CA15127 RECODIS and possible investigations together with the research group from the Institute of Microwave and Photonic Engineering of Graz University of Technology.

- *familiarization with the laboratories* and equipment in there, which is used in Optical Wireless communications;
- *analytical investigation* of the behavior of Optical Wireless links in presence of different weather conditions, more specifically focusing to the influence of it to the Free Space Optics systems.

The main points, that were interesting to STSM grantee from a lot of investigations carried out by the research group of the Institute of Microwave and Photonic Engineering are presented in the next sections below.

2.1 Introduction to Optical Wireless Systems

Optical Wireless systems are the good example of the integration between optical and wireless radio communications, where the light of different types is caring the main signal for data transmission over the atmospheric channel. Optical Wireless systems have huge advantages in comparison to other communication types [1]:

- ultra-high bandwidth capacity,
- robustness to electromagnetic interference,
- a high degree of spatial confinement bringing virtually unlimited frequency reuse,
- inherent physical security,
- low power requirements,
- unregulated spectrum,
- cost-effective solution for different applications.

The basic Optical Wireless system consists of three main parts (Fig. 1) - source system (optical transmitter, a modulator and an irradiation device – a telescope or a lens), channel for signal transmission and receiver system (a detector, a decoder, and a telescope or a lens).

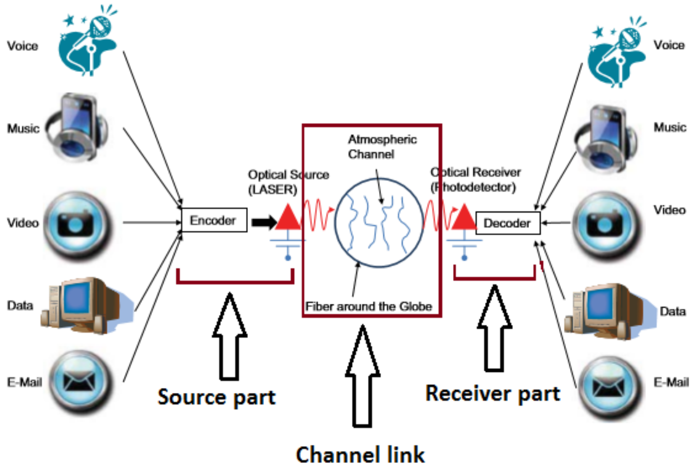


Figure 1. Structure of Optical Wireless communication system [modified from [2]]

In OW system, the information from the optical transmitter is modulated on a collimated beam of light, which is projected through free air channel onto the receiver side [2]. The channel for signal transmission is a free space (air). The modulation and demodulation is direct. Since the medium for signal carrier is a light, such system operating frequencies are very high and range from 300 GHz to 300 PHz. It includes infrared (750 nm – 1mm), visible (390-750 nm) and ultraviolet bands (200-280 nm) [1]. Due to this, Optical Wireless communication can be classified into Free Space Optics (FSO), Visible Light Communication (VLC) and Ultraviolet Communication (UVC).

FSO, known as terrestrial point-to-point OW communication system, offers a cost-effective protocol-transparent link with high data rates (as 10 Gbps per wavelength). Such system allows to set up communication links between two locations whenever a free line of sight is present [1]. Typical wavelength of Free Space Optics system ranges from 800 to 1700 nm. In [3] were presented, that Free Space Optics links, installed between building-to-building communication, using 16-wavelenght each at 100 Gbps reached 1.6 Tbps data transmission. Such Optical Wireless communication system can be used in cellular backhauls, wireless MAN extensions, WLAN-to-WLAN connectivity in different environments, broadband access to remote or underserved areas and *etc* [1]. Due to this, Optical Wireless system can be used not only for temporal installations as conferences, special events, but as well in the face of a crisis for emergency and medical needs or permanent connections in last mile access without cabling.

Free Space Optics are easy to install and it is redeployable, so this type of OW communication is particularly useful as redundant links in disaster situations, where local infrastructure could be damaged or unavailable. It was used as a redundant link in New York after the terrorist attacks on 11th of September, 2001 [4].

2.2 Impact of different atmospheric and weather conditions to the links of Optical Wireless System

As it was mentioned in previous section, the optical communication links can operate in high frequencies and allow very fast data transmission in comparison to other communication types. However, a key disadvantage of Optical Wireless systems is it sensitivity to atmospheric conditions and limited reliability.

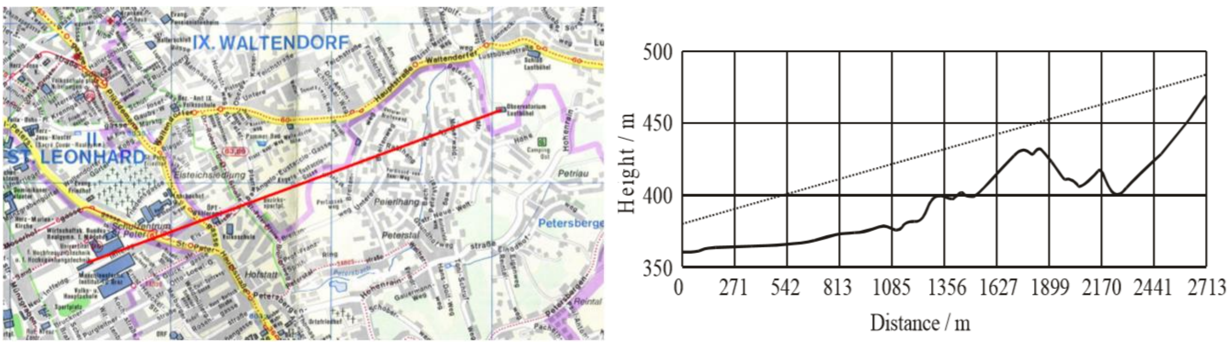
The atmosphere is composed of gas molecules, water vapor, aerosols, dust and pollutants, whose sizes are comparable to the wavelength of a typical optical carrier affecting the carrier wave propagation not common to a radio frequency (RF) system [2]. Absorption and scattering due to particulate matter may significantly attenuate the transmitted optical signal, while the wave-front quality of a signal-carrying laser beam transmitting through the atmosphere can be severely degraded, causing intensity fading, increased bit error rates, and random signal losses at the receiver. Turbulence also has the impact on OW communication as a finite-sized optical beam faces diffraction, which broadens the beam and it propagates in the deterministic medium. It results more beam spread at the receiver side [1]. Also, the turbulence causes the fluctuations in the intensity, which degrade the communication performance quality by reducing the bit error rate; degrades the focusing of the beam on the required spot and impacts a beam quality factor, known as M^2 propagation factor.

The atmospheric channel for signal propagation over FSO communication has to deal with many external factors related to the different weather conditions [5]: rain, fog, sleet, snow, smog, clouds, different kinds of aerosols, variations in temperature and *etc.* All these weather conditions affect the wireless systems and Optical Wireless systems as well. It is just a difference in a scale of the affect to the parameters of OW communication performance.

The research group of the Institute of Microwave and Photonic Engineering, TU-Graz has done a lot of work by investigating the impact of different weather conditions to the Optical Wireless communication, especially Free Space Optics systems.

Influence of fog

One of their first evaluation test was done with a Multi-beam system, starting in July 2000 [6]. This system was installed to connect the Department of Communications and Wave Propagation („Studienzentrum, Inffeldgasse 10“) to the „Observatory Lustbühel“ [12], see Fig. 2. The distance between FSO units was 2.7 km.



a) b)

Figure 2. a) FSO connection between “Studienzentrum” and „Observatory Lustbühel“, b) terrain profile [12]

Test data at 155 Mbps (STM-1) provided by an ANT-20 BER-Tester (Wandel&Golterman) was sent from one FSO-unit to a distant FSO-unit. The received data was sent back (loop) to the first unit. As a reference to the link quality, weather data was recorded (including temperature, humidity, wind speed and direction and rain rate). Figure 3 shows the results of FSO communication availability per year. The authors of this work stated, that the main cause for failure in the marked period (in Fig. 3) was fog, as the sum of time of falling snow was much shorter than the sum of time of fog, and during the measurements falling snow appeared always together with fog so that the optical connection already failed before the effect of snow could be shown

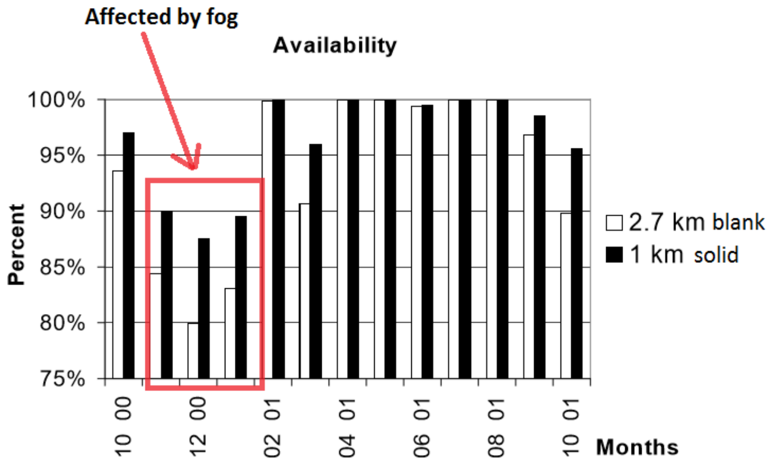


Figure 3. FSO communication availability during one year [modified from [6]]

In figure 4 it is shown the results from the investigations on September, in 2005, at Graz. It was compared the fog attenuation for 850 and 950 nm wavelength (a transmissiometer operating at 550 nm is not available for the measurements at Graz).

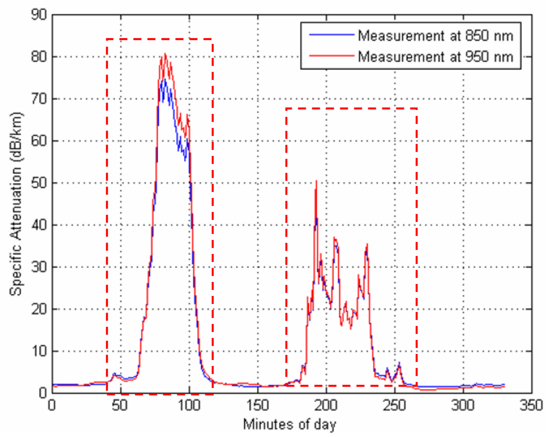


Figure 4. Fog influence to FSO communication [7]

It was found indications for less attenuation at 850 nm wavelength. It could happen for several reasons: *firstly*, for radiation fog particle diameters are in the same order of magnitude than the wavelength. If the diameters are mostly cumulated around a certain value, the shorter wavelength can be less attenuated. *Secondly*, it could be based on the spatial transmission properties in this type of fog, as the transmitters for 850 and 950 nm in Graz have different beam divergence angles.

In generally, fog and water clouds mostly affect FSO links due to the size of it droplets. The size of droplets is of the same order of magnitude as wavelength, which implies a high extinction efficiency, and their concentration is much larger than the one of rain or snow. In [8] it is calculated the attenuation of fog (Fig. 5), which clearly shows the scale of fog impact to the signal attenuation.

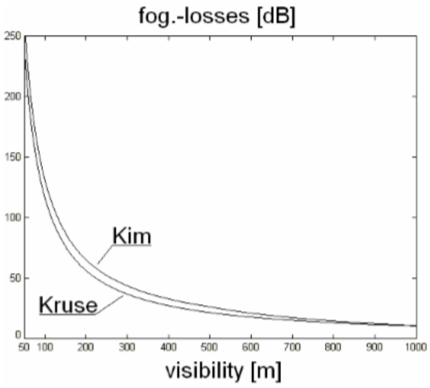


Figure 5. Calculation of fog influence to FSO communication [8]

Influence of rain

Rain is also an important attenuator for the optical signals. It is the main disturbance for the microwave links, especially thunderstorms. The rain attenuation was calculated in [8].

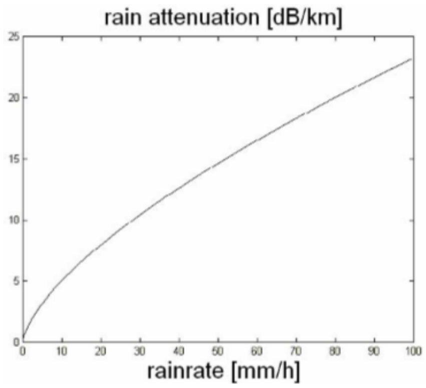


Figure 6. Calculation of rain influence to FSO communication [8]

Figure 7 shows the results of another investigation of a research group. They found, that in period of a drizzle the mean power was decent by 2.5 dB at a rain rate of 2 mm/h. At the start of heavy rain with an average rain rate of 5 mm/h, accordingly the received power decent by 6 dB.

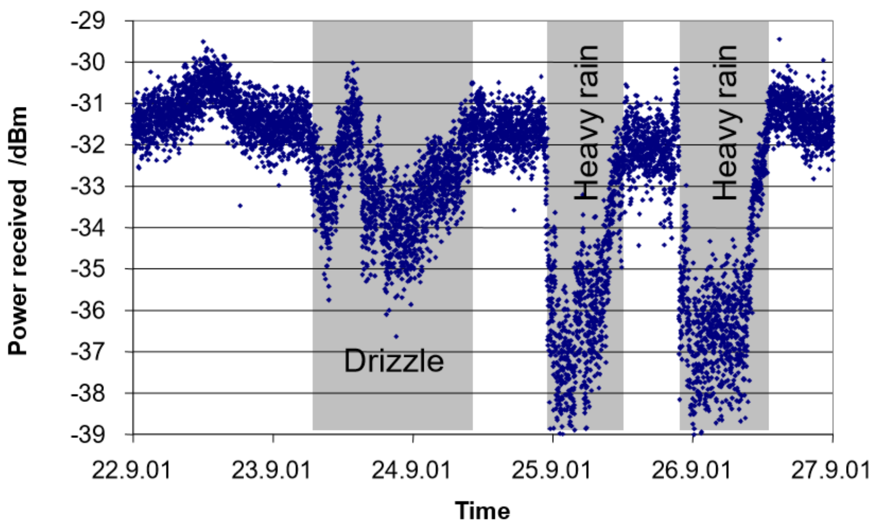


Figure 7. Rain influence to Optical Wireless link [9]

Influence of snow

The attenuation due to snow fall has been modelled based on dry or wet snows [8]. Snow is usually constituted by aggregates of ice crystals. However, snowflakes have irregular shape and different compositions.

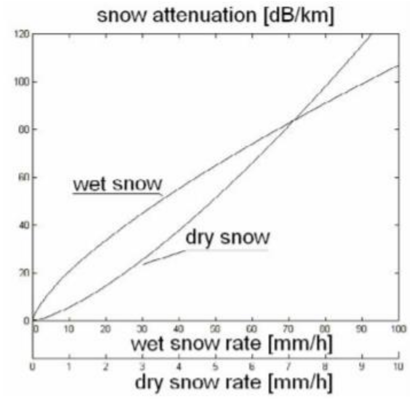


Figure 8. Calculation of snow influence to FSO communication [8]

At microwave frequencies, the effect of snow is smaller than the one due to rain, however laser attenuation by falling snow can exceed 40 dB/km, depending on water content of snowflakes and on precipitation rate.

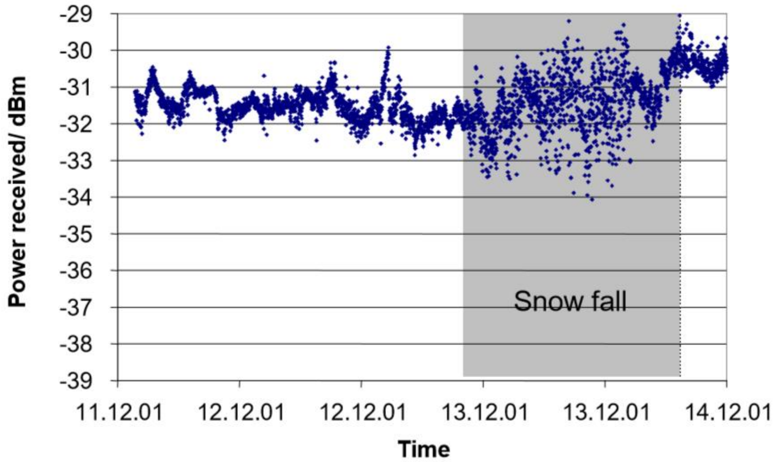


Figure 9. Snow influence to Optical Wireless link [9]

In the investigation, which results are presented in Fig. 9, the received mean power of OW link stays unchanged, but the variance is increased significantly.

It was also proofed [13], that the direction adjustment can be slightly changed by other weather conditions, as variation of temperature and the sunlight. It can change the transmission characteristics of optical band pass filters and laser diodes or at the receiver side can occur a failures due to voltage peaks or heat.

Summary of causes, according to [10] for reduced transmission quality or link failures in FSO systems may be:

- the local weather situation (especially fog and precipitation),
- direct sunlight at the receiver,
- turbulences in the air,
- beam misalignment,

- soiled optical components (like mirrors, glasses and lenses),
- Component aging.

In general, all these aspects could be the reason for the higher vulnerability of Optical Wireless systems and it could cause a reduced resilience of such communication.

2.3 Ways to increase the resilience of Optical Wireless systems

Many approaches and works have been done by investigating the best way to increase the resilience of Optical Wireless systems.

Firstly, it is necessary to increase the channel capacity and the availability of Optical Free Space Links. This seems achievable with the following techniques and methods as [10]

- special coding,
- auto tracking in combination with Automatic Gain Control,
- transmission of short Pulses (and other modulation techniques) in regard to Laser- and Eye Safety instead of Intensity modulation,
- standardization,
- development of new equipment for Optical Free Space Communication,
- in Combination with microwave backup (as Wireless LAN)

Secondly, if we are talking about the quality of service in a shape of data transmission availability, then it can also be possible to use short periods of less attenuation [11] within high average attenuation time to transmit data bursts and so to have still some data throughput, if higher latency can be accepted for the type of service.

Thirdly, the combination of different technologies in Optical Wireless communication would help to improve the availability of the OW links.

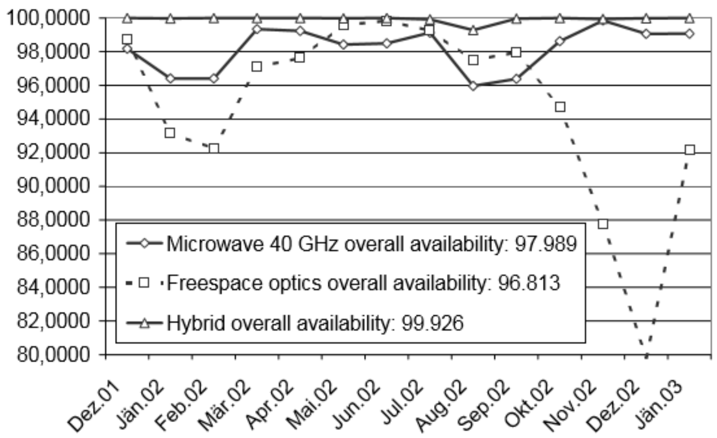


Figure 10. Investigation of the availability of separated links and hybrid communication [12]

The good proof of that is in [12], when it was founded, that the combination of microwave and free space optics can improve the availability of the link (see Fig. 10), but to achieve an availability of 99,999%, the system has to overcome the heavy thunderstorms. This means that one system has to manage the high losses, which might render the hybrid unnecessary.

3. The main results obtained within this work

Dr. Rasa Bruzgiene has presented her research topic within the RECODIS WG2 in Wroclav meeting. The main results, which prof. Dipl.-Ing. Dr. Erich Leitgeb with his team got from many investigations in Optical Wireless communication systems, are very important and will be used in further research work of R. Bruzgiene.

Generally, the characteristics of Free Space Optics system and it changes in the face of fog, snow or rain showed the behavior of the OW link and the possible beginning of the disruption (Fig. 11).

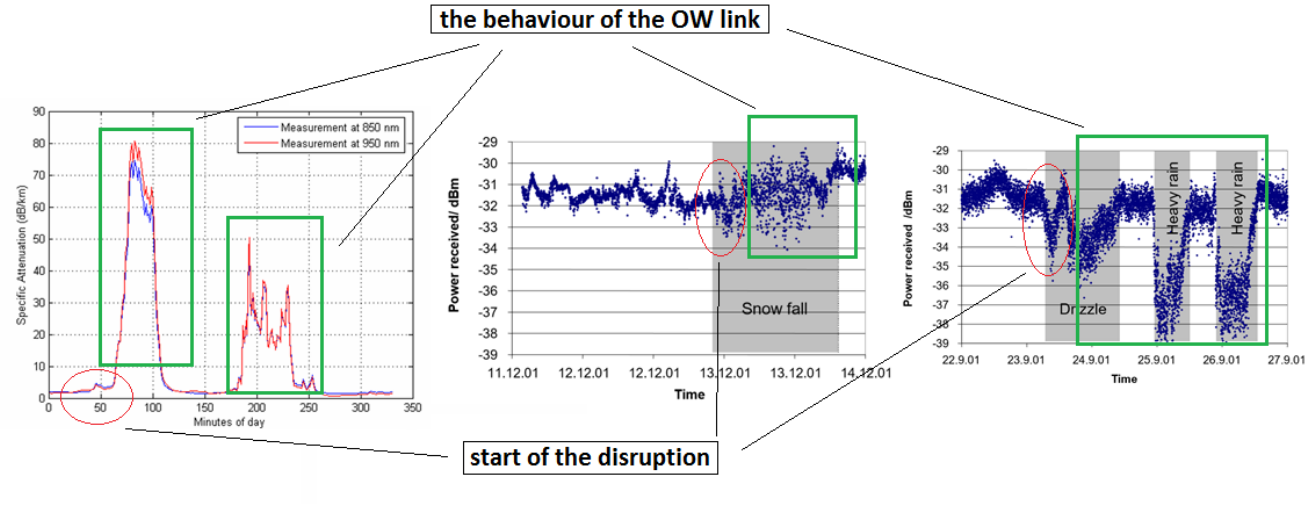


Figure 11. The start of the weather-based disruptions and behavior of OW link during it

It raises very important and related with QoS (Quality of Services)/QoE (Quality of Experience) in Optical Wireless communication questions, which should be investigated in later joint investigations with host team:

- What was the impact of the weather conditions to the parameters of a transmitted service (ex.: rate of data transmission, data losses, bitrate errors, *etc*.) in the beginning of the disruption?
- What was the impact of the weather conditions to the parameters of a transmitted service in the peak of the disruption?
- How the behavior of the OW link during the weather-based disruptions affected the perceived quality of the service users?

The answers to it should help to use a relation between QoS parameters and QoE metrics in creating a solution for an alert in order to react and prevent service performance degradation under the weather-based disruptions in such systems.

4. Future collaboration with the Host institution

Based on the fact, that the host Prof. Dipl.-Ing. Dr. Erich Leitgeb and the STSM grantee dr. Rasa Bruzgiene had met at first time during this STSM period, it was decided between them to collaborate in joint investigations, papers and conferences on the topics that will arise within COST RECODIS WG2 activities.

5. Foreseen publications/articles resulting from the STSM

It was decided to submit joint papers to:

- IEICE Information and Communication Technology Forum 2017**,** which will be held on 4th-6th of July, 2017 in Poznan, Poland;
- 12th International conference on Communications, Electromagnetics and Medical Applications (CEMA'17), which will be held on 12th-14th of October, 2017 in Sofia, Bulgaria.

Also, the further joint investigations and results arising from it will be presented in next COST RECODIS meeting as well as published in scientific journals.

6. References

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