EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

SHORT TERM SCIENTIFIC MISSION (STSM) SCIENTIFIC REPORT

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

Action number: COST CA15127 Action, STSM reference number: 38837
STSM title: Investigation of OWC links under various atmospheric effects with a special focus on the state of the art car to car OWC scenario
STSM start and end date: 29/10/2017 to 11/11/2017
Grantee name: Hristo Ivanov

PURPOSE OF THE STSM:

Free Space Optical (FSO) systems are well-known in terms of their enormous bandwidth and their high data rates respectively. One area where their application could be particularly important is in vehicle to vehicle communications where till now mainly the Radio Frequency (RF) communication techniques are used. However the RF technology itself has a lot of problems in terms of reliability which have to be considered. This includes packet collisions and longer delays as well as link disruptions due to weather conditions. One solution is to substitute the RF technology with Optical Wireless Communication (OWC) technology. On the other hand, the performance of radio frequency RF transmission can be increased by building a hybrid link including a OWC system. These two technologies have very good complementary behavior in terms of atmospheric effects. Moreover, OWC has enormous bandwidth which allows very high data rates. Consequently OWC can evidently contribute for the reliability and higher capacity of the communication system in the presence of various weather-based disruptions, which is the main goal of Working Group 2 (WG2). While RF technology is well examined and mature one, the OWC technology is still faced by various unmitigated problems related mainly to the atmospheric channel. Respectively, my Short Term Scientific Mission (STSM) will be focused on different atmospheric perturbation effects and more specifically their influence over car to car optical wireless communication link. The main degradative atmospheric effects, which will be examined are absorption, scattering and turbulence. However, another issues such as noises can be also considered. The OWC car to car communication allows essential data such as speed, position, distance, brake status, steering-wheel position and all other important information to be transmitted. Regarding the above discussion, the main attained goals during my research in the frame of COST action CA15127 RECODIS, WG2 are:

- Short comparison between car to car RF and OWC communication link
- Possibility to expand my knowledge and research in terms of atmospheric effects which influence car to car FSO channel. Due to selection of an appropriate transmission window and more specifically wavelength, in the most of the cases absorption can be neglected. However the severe attenuation due to scattering and turbulence (scintillations) effects have to be considered. This initial theory was important to accomplish the next steps of my working plan.
- Introduction to the special design of OWC car to car communication which reuses Light Emmiting Diodes (LEDs) and cameras already available in the vehicles. The transmission is based on daytime running lamps, brake lights, etc. On the other hand, cameras installed in the cars for the assisting parking can be used for data receivers.
- Improving and developing car to car communication channel model simulations for evaluation of different OWC scenarios in terms of various atmospheric effects. The models includes parameters such as wavelength, collect view angle, path length, visibility, fading.

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- Participation in laboratory measurements which provided me with enough knowledge to prove the concepts already developed in the previous considerations and results. Regarding the special car to car OWC, a refracted optical signal will be also considered during the future measurements. In other words, together with the line of sight optical signal, also the reflected one will be taken into account.

To sum up, the present STSM in frame of COST action CA15127 RECODIS is very narrow related to WG 2, which main objective is to increase the reliability of end to end communication links in the presence of different atmospheric distortion problems. Implementation of FSO systems in parallel with RF technology is only one of the possible ways for the completion of the above task.

DESCRIPTION OF WORK CARRIED OUT DURING THE STSMS

In the frame of the current STSM I have a scientific research stay in University of Las Palmas de Gran Canaria, IDeTIC (research Institute of the University of Las Palmas de Gran Canaria). My stay includes different activities mainly related to the following:

- I was part of the Optical Group of Prof. Rafael Perez and participated in research related to car to car optical communication links
- I gave a few presentations in terms of my main PhD research as well as my accomplished work in the frame of the current STSM
- Getting familiar with various wireless car to car communication technologies, including also RF, with special focus on optical wireless car to car communications.
- I have daily discussions with Prof. Rafael Perez and his team related to the optical channel characterization and modelling of car to car OWC links. The topic for implementation of a real vehicle to vehicle OWC system was also considered.
- Accomplishing analytical studies in terms of wireless optical car to car atmospheric communication links. This includes different atmospheric effects which can cause severe and undesirable weather-based disruptions
- Participation in laboratory experiments in IDeTIC related to optical car to car communications

Apart from this, during my research stay in University of Las Palmas de Gran Canaria, IDeTIC I also visited European Space Agency Optical Ground Station in the Teide observatory, Teneriffe, Spain. There, I have possibility to be introduced to real optical space communication technologies. In other words I have a discussion over channel characterization in terms deep space optical communication links. This also includes different mitigation methods for decreasing the attenuation due to turbulence as well as other weather-based disruptions which directly related to WG 2. A special focus was put on adaptive optics which is used as an effective way for fighting the turbulence effect. All this activity was very helpful in terms of current research in this area.

The initial part of my STSM was to compare and consider both RF technology as well as FSO system as a possible solution for future car to car communication scenarios. This also includes hybrid system solution which can delivere very good results in terms of mitigation of the weather-based disruptions. However the most important task of the current STSM is to investigate the still immature optical car to car communication link itself with special emphases on the atmospheric effects. On the one hand, this knowledge are very important in terms of implementation of the optical link in a Hybrid RF/OWC related to WG 2. On the other hand this examination provides better overview of the problems related to the atmospheric effects. This report delivers a basic observation of the accomplished work

The standard for vehicle to vehicle radio frequency communication is IEEE 802.11p. In IEEE 802.11p a simplified version of carrier sense multiple access with collision avoidance (CSMA/CA) is chosen as the medium access control (MAC) layer protocol. However this type of RF communication deliver a lot of problems in terms of reliability which have to be considered. RF-based vehicular communications experience packet collisions and longer delays as well as poor packet reception rate. Limited RF bands have already been allocated to operate cooperative in Europe (30 MHz). Currently, the impact of car to car communications on the amount of RF spectrum usages is low, but this is expected to significantly increase in the near decade. Such small RF bands can quickly suffer from interferences when hundreds of cars located in the same area try to communicate all together. In addition, RF communications are also dependent from the weather situations, and more specifically problems such as rain, etc. Based on the above listed problems, it is clear that RF technology cannot provided enough reliability for car to car communications. This is the reason that in this STSM we consider OWC technology as a possible solution for the vehicle to vehicle communication link. The main positive features of wireless optical communications are the high bandwidth (data rates) intrinsic immunity to the electromagnetic interference, operation in unlicensed bands, inherent safety and security and a high value of the reuse factor. In addition, OWC based positioning technology is able to reduce the positioning error to tens of centimeters, which is more accurate than the RF based positioning technology. Moreover, LEDs have been used for diverse light sources in vehicles, including daytime running lamps, headlights, taillights, brake lights, and front/rear frog lamps. Meanwhile, cameras deployed in vehicles for the driving image recording and automated parking are considered as data receiving applicants and shared with the original functions. This advantages together with the low cost and low complexity make OWC technology very important for vehicle to vehicle communications. However FSO communication link can be severelly degraded because of the atmospheric effects. In comparison with RF technologies where the main transmission issues are due to rain, here the tramission isuses are due to fog and turbulence [1],[2].

Troposheric fog effect can be divided in two types, namely maritime and continental fog which differ in the amount of the imposed attenuation. The maritime fog is similar to clouds and as a result can cause attenuation hundreds of dB/km. Moreover this event is very unstable with fluctuations of hundreds of dB for one second period. In case of continental fog the attenuation is considerably lower with a peak around 100 dB/km. In addition, the variations of the attenuation are small or in other words the continental fog is significantly stable. The another problem is because of the turbulence. Depending on the size of atmospheric turbulence cells two different effects are possible, namelly scientlation or beam wondering. More specifically this can be a problematic issue in areas where the road temperature is high due to the strong solar radion. Considering also car to car non-coherent optical communication source, the turbulence effect can be a significant problem. In other words several meters above the high temperature road, severe wave front distortion are possible, which can influence very seriously the optical information transmission [3],[4].

In Figure 1 the developed and available testbed in IDeTIC for evaluating the car to car OWC in laboratory conditions is shown. This setup is used for verification of the hardware related optical car to car communications.

Figure 1 Testbed for investigation of optical car to car communication systems

The block diagram related to the shown above setup is presented in Figure 2. It includes four blocks, namely: car computer emulator, optical transmitter (car headlights), optical channel, detector (PIN photodiode)

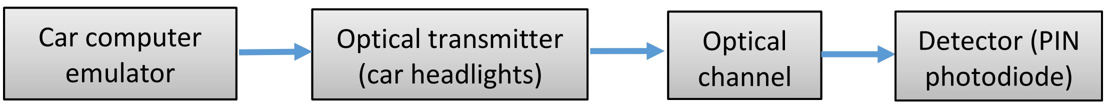

Figure 2 Architecture of the Testbed for investigation of car to car OWC systems

The main goal of the car computer emulator is to represent properly the processing and to transmit the data which normally are used from the cars in terms of an accurate vehicle control. Once the data are simulated with the developed emulator, they are transmitted in the optical domain with help of car headlights. Normally, car headlights are a non-coherent light sources with significant divergence angle which transmit optical signal in the visible part of the spectrum. Their illumination is described by isocandela and isoilluminance diagrams. After the optical channel where real atmospheric conditions can be emulated in different ways, there is an optical detector. In the current laboratory setup the detector is a PIN photodiode. However, in real conditions also other possibilities such car cameras can be used.

Apart the work with the hardware, channel modeling and simulations are accomplished. In other words, in the following part we will give a short introduction for the developed and applied model. The basic parameters which are used for the introduced car to car OWC channel modeling and characterization are provided in Table 1.

Parameters	Name	Units
Luminous intensity of the headlights	$I_{sc}(\varphi_v\varphi_h)$	Cd
Headlight horizontal angel	φ_v	rad
Headlight vertical angel	φ_h	rad
Distance between Tr. and Rec.	d_{sc-r}	0-60 (m)
Azimuthal angle (road)	β	rad
Incidence angle (road)	γ	rad
Incidence angle LOS (detector)	ϕ_{los}	rad
Incidence angle NLOS (detector)	ϕ_{nlos}	rad
Field of view of photodetector (PD)	ϕ	rad
Luminous efficiency of radiation	*LER*	lm/W
Visibility	*V*	km
Mie scattering coefficient	α_e	1/m
Illuminated road area	*S*	m^2
PD effective active area	A_r	mm^2
Small scale eddies	*a*	-
Large scale eddies	*b*	-
Random coefficient (gamma-gamma)	h_t	-

Table 1 Parameters used in the channel modelling

In car to car optical communications two different channels have to be taken into account when the link characterization is accomplished. The first one is the ordinary line of sight (LOS) link. The second one is more interesting because is non light of sight (NLOS) channel and comprise the refracted transmitted headlight optical signal from the road surface. The most important roads are classified in Table 2, based on three parameters. The most significant parameter is the custom made r-table which is dependent on the specific weather conditions as well as road material.

Standard table	Q_0	*S1*	Description
C2	0.07	0.966	Asphalt
R1	0.10	0.247	Mostly diffuse
R2	0.07	0.582	Mixed (diffuse and specular)
R3	0.07	1.109	Slightly specular
R4	0.08	1.549	Mostly specular
W1	0.11	3.152	Wet road surface

Table 2 Road classification

After an r-table is developed, the refracted intensity from the road surface can be calculated from the equation (1) which is derived based on theoretical analysis.

$$\mathrm{dP_{rnlos}} = \frac{\mathrm{r(\beta, tan(\gamma))dI_{sc}(\varphi_v\varphi_h). \cos\phi_{nlos}A_r}}{\mathrm{h_{sc}^2 LERd_{A-r}^2}}\mathrm{dS} \quad (1)$$

Based on the equation (1), the total received NLOS link optical power is calculated in terms of integartion over all road surface S. In addtion the field of view angle of photodetector ϕ has to have a higher value than incidence angle of NLOS ϕ_{nlos}.

$$P_{rnlos} = \begin{cases} \iint_S dP_{rnlos} dS & 0 \le \phi_{nlos} \le \phi \\ 0 & \phi_{nlos} \ge \phi \end{cases} \quad (2)$$

Once the received power related to the NLOS link is calculted, the next point is to be considered the optical power transmitted through the LOS link.

$$P_{rlos} = \frac{I_{sc}(\varphi_v \varphi_h) \cos \phi_{los} A_r}{LERd_{sc-r}^2} \quad (3)$$

Similar to the equation (2), the LOS optical power will be received only if the LOS incidence angle is smaller than the field of view angle of the optical detector. Finally from equation (2) and (3) the total optical power can be calculated. When the received optical power is already available, the next step is to be considered different atmospheric effects which lower the reliability of car to car optical communications. The main tropospheric influences are related to the turbulence and fog effects. Regarding the turbulence the applied distribution is Gamma - Gamma one. This distribution allows strong as well as weak turbulence to be enough well represented.

$$P(h_t) = \frac{2(ab)^{\frac{a+b}{2}}}{\Gamma(a)\Gamma(b)} h_t^{\frac{a+b}{2}+1} K_{a+b}(2\sqrt{abh_t} \quad (4)$$

In addition to the turbulence, also different fog conditions are considered. The empirical equation related to the Mie scattering is provided below. As it is visible, the equation is completely dependent on the visibility V which can reach tens of meters till tens of kilometers.

$$\alpha_e = \frac{3.91}{V}\left(\frac{\lambda}{550nm}\right)^q \quad (5)$$

$$q = \begin{cases} 1.6 & if\, V > 50km \\ 1.3 & if\, 6km > V > 50km \\ 0.585V^{1/3} & if\, V < 6km \end{cases} \quad (6)$$

Based on the shortly introduced above sophisticated hardware and channel characterization different investigation are possible. Apart from this, the developed algorithm and already available hardware can be easilly applied together with RF communication system for checking hybrid OWC/RF link.

DESCRIPTION OF THE MAIN RESULTS OBTAINED

In the current section, part of the important results in terms of the STSM are presented. This data gives a good overview over the shortly presented above developed theoretical approach. Regarding optical car to car communications, one of the most important parts is the derivation of a correct (refraction) r - table for the specific road conditions. In our case this is accomplished for normal asphalt which is in mostly dry and not considerably wet environment. The measured results are shown in Table 3.

β	0	2	5	10	15	20	25	30	35	40	45	60	75	90	105	120	135
tanγ																	
0	329	329	329	329	329	329	329	329	329	329	329	329	329	329	329	329	329
0.25	362	358	371	364	371	369	362	357	351	349	348	340	328	312	299	294	298
0.5	379	368	375	373	367	359	350	340	328	317	306	280	266	249	237	237	231
0.75	380	375	378	365	351	334	315	295	275	256	239	218	198	178	175	176	176
1	372	375	372	354	315	277	243	221	205	192	181	152	134	133	125	124	125
1.25	375	373	352	318	265	221	189	166	150	136	125	107	91	93	91	91	88
1.5	354	352	336	271	213	170	140	121	109	97	87	76	67	65	66	66	67
1.75	333	327	302	222	166	129	104	90	75	68	63	53	51	49	49	47	52
2	318	310	266	180	121	90	75	62	54	50	48	40	40	38	38	38	41
2.5	268	262	205	119	72	50	41	36	33	29	26	25	23	24	25	24	26
3	227	217	147	74	42	29	25	23	21	19	18	16	16	17	18	17	19
3.5	194	168	106	47	30	22	17	14	13	12	12	11	10	11	12	13	15
4	168	136	76	34	19	14	13	11	10	10	10	8	8	9	10	9	11
4.5	141	111	54	21	14	11	9	8	8	8	8	7	7	8	8	8	8
5	126	90	43	17	10	8	8	7	6	6	7	6	7	6	6	7	8
5.5	107	79	32	12	8	7	7	7	6	5							
6	94	65	26	10	7	6	6	6	5								
6.5	86	56	21	8	7	6	5	5									
7	78	50	17	7	5	5	5	5									
7.5	70	42	14	7	4	3	4										
8	63	37	11	5	4	4	4										
8.5	60	37	10	5	4	4	4										
9	56	32	9	5	4	3											
9.5	53	28	9	4	4	4											
10	52	27	7	5	4	3											
10.5	45	23	7	4	3	3											
11	43	22	7	3	3	3											
11.5	44	22	7	3	3												
12	42	20	7	4	3												

Table 3 Refraction r – table for dry Asphalt

In the r-table above each of the values correspondence to the reduced luminance coefficient `r` which depends on the angle of incidence γ and the angle β between vertical plane of incidence and the vertical plane of observation. After this information is already available, each point of the road can be characterized with exact amount of the refracted power. Nevertheless, for the current report containing only basic description of the problem, only LOS link will be shown. The main reason is that the LOS link transmits the main amount of the optical power which is received by the optical detector. The simulations are related to the specifications of the real developed hardware in IDeTIC shown in Figure 1. In other words, the datasheets of car highlights are used and also a PIN photodiode with normal sensitivity of -28 dBm is applied.

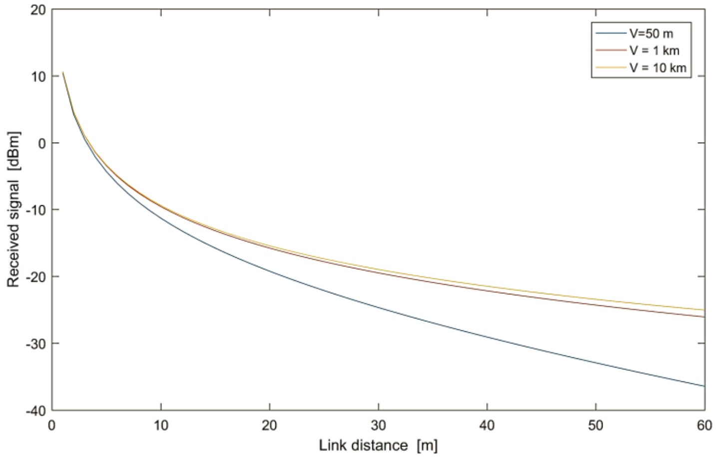

Figure 3 Received signal versus link distance for different types of visability

As it is visible from Figure 3 the LOS link is not so dependent on the fog due to the short distance between the cars. However, when the fog is very strong, namely the visibility is very low, the attenuation can reach significant value of 10 dB. The maximum distance of 60 m is used due to the requirements for the safe distance between cars. In Figure 4 the recommended distance between vehicles versus vehicle speed is shown. The calculations are prepared in terms of the requirements for the safe driving.

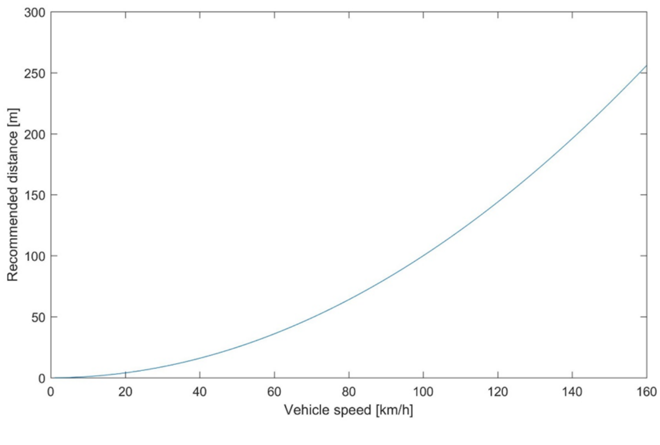

Figure 4 Recommended distance versus vehicle speed

Apart from the above results, also the current STSM was involved in the NLOS car to car link simulations as well as simulations related to different turbulence conditions. In addition, also differnts noises such as quantum and temperature noise were considered. The link characterization could be very helpful in terms of future enhancements of the already developed simulation hardware. In this way the real implemented system can have the necessary durability to work in different problematic weather conditions or in other ways to have resistance to the weather based disruptions (WG 2)

FUTURE COLLABORATIONS (if applicable)

In the frame of my STSM part of COST RECODIS action, I successfully obtained important knowledge and skills in terms optical car to car communication technology. My main work was to accomplish a channel characterization and modelling for car to car optical link. On the one hand, this gave the possibility to prove the reliability of the car to car optical communication scenarios in the presence of various atmospheric condition. On the other hand, this provides me with possibility to test concept based on real hardware. Development of a Hybrid OWC/RF car to car communication system is only one of the possibilities the atmospheric weather based disruptions (WG2) to be overcome. Apart from the above simulations, I also participated in experiments with specially developed laboratory testbed in IDeTIC. In this way I had possibility to operate with a real car to car optical communication link containing non-coherent car headlight source.

Based on the already presented results, I will continue the narrow collaboration with University of Las Palmas de Gran Canaria, IDeTIC. With Prof. Rafael Perez I have already discussed the possibility for participation in a real experiment where the optical communication modules are installed in real vehicles. This experiment will give the possibility to be verified the results from the channel modelling simulations. More precisely this will give possibility to be tested the system in different fog as well as turbulence conditions. Both of the them normally leads to weather based disruptions.

One of the possible conferences where the results of the current collaboration can be published is: 2018 11th International Symposium on Communication Systems, Networks and Digital Signal Processing (CSNDSP) Budapest, Hungary

Also the results can be considered for a contribution to the RECODIS book or another journal.

References

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