

# **COST**

Domain Committee "Information & Communication Technologies"

## **COST Action IC1101**

**Start Date 08/11/2011**

*Optical Wireless Communications - An Emerging  
Technology (OPTICWISE)*

## **MONITORING PROGRESS REPORT**

***Reporting Period: from 1st May 2012 to 30<sup>th</sup> April 2013***

This Report is presented to the relevant Domain Committee.  
It contains three parts:

- I. Management Report prepared by the COST Office/Grant Holder***
- II. Scientific Report prepared by the Chair of the Management Committee of the Action***
- III. Previous versions of the Scientific Report; i.e., part II of past reporting periods***

The report is a "cumulative" report, i.e. it is updated annually and covers the entire period of the Action.

Confidentiality: the documents will be made available to the public via the COST Action web page except for chapter *II.D. Self evaluation*.

Based on the monitoring results, the COST Office will decide on the following year's budget allocation.

**Executive summary (max. 250 words):**

COST Action IC1101 OPTICWISE has continued its activities with the 3<sup>rd</sup> MC Meeting which took place on October 2012 in Pisa, Italy. The 1<sup>st</sup> Annual Workshop was also held in conjunction with the MC meeting. It was highly successful and able to attract participants outside the Action. We further organized a training school on February 2013 in Northumbria, UK providing a unique hands-on experience for early stage researchers.

Our Action had adopted a mixed structure of “horizontal” and “vertical” organization through the introduction of topic-focused WGs and application-focused SIGs. We have already seen early positive outputs of this strategy in terms of increased collaboration. The Action participants produced a total of 207 publications 29 of which are as a result of COST networking through the Action. The recent launch of the researcher information database has been also instrumental in igniting collaboration among Action participants.

The Action has also established contacts with the relevant major standardization bodies and the global forums such as ITU, URSI, IrDA, Li-Fi as well as some other COST Actions and FP7 projects. In terms of dissemination activities, we have launched the website of the Action as well as OPTICWISE accounts in social networks (Facebook, LinkedIn, Twitter). We prepared a leaflet which provides general information and overall activities of OPTICWISE and distributed by both e-mail and postal mail. We also publish a semi-annual newsletter highlighting the latest achievements and public deliverables of the Action.

## I. Management Report prepared by the COST Office/Grant Holder



### I.A. COST Action Fact Sheet

- **COST Action:** IC1101 Optical Wireless Communications - An Emerging Technology (OPTICWISE)
- **Domain:** ICT

- **Action details:**

**CSO Approval:** 17/05/2011                      **End date:** 07/11/2015  
**Entry into force:** 27/06/2011                **Extension:** -

- **Objectives** (from DB as in About COST)

The aim of COST Action OPTICWISE is to increase the scientific understanding and technical knowledge of the emerging field of optical wireless communications (OWC) by exploring and developing novel methods, models, techniques, strategies and tools in infrared, visible and ultraviolet spectral bands that will facilitate the implementation of future generations of OWC systems. The resulting high-performance, high-reliability, ultra-fast, power-efficient, and low-cost OWC systems are envisioned as an indispensable part of a future wireless eco-system. OPTICWISE will help establish OWC as a mature communication technology and present a powerful alternative and/or complement to existing technologies in a diverse range of communication applications.

Besides enabling scientific advances in the emerging field of OWC, OPTICWISE will also serve as an internationally recognized reference point through capacity building of OWC stakeholders. It will increase awareness of OWC in the scientific community and the general public. It will influence decision makers at national and international levels through the participation in standards bodies, international forums and workshops, etc. It will also provide training opportunities for the graduate students and early-stage researchers (ESRs) in the OWC field.

- **Parties:** list of countries and date of acceptance

Austria (30/06/2011)	Greece (02/08/2011)	Poland (13/07/2011)
Belgium (28/09/2011)	Hungary (08/09/2011)	Portugal (27/06/2011)
Bulgaria (n/a)	Iceland (n/a)	Romania (28/02/2012)
Croatia (n/a)	Ireland (11/08/2011)	Serbia (04/06/2012)
Cyprus (14/10/2012)	Israel (12/07/2011)	Slovakia (n/a)
Czech Rep. (15/06/2011)	Italy (15/06/2011)	Slovenia (12/07/2011)
Denmark (n/a)	Latvia (n/a)	Spain (07/07/2011)
Estonia (n/a)	Lithuania (n/a)	Sweden (27/10/2011)
Finland (13/10/2011)	Luxembourg (n/a)	Switzerland (n/a)
FYR of Macedonia (n/a)	Malta (n/a)	Turkey (16/06/2011)
France (12/08/2011)	Netherlands (n/a)	United Kingdom (16/06/2011)
Germany (05/07/2011)	Norway (n/a)	

- **Intentions to accept:** Denmark, The Former Yugoslav Republic of Macedonia
- **Other participants:** Chosun University (Republic of Korea), Monash University (Australia), National University of Computer and Emerging Sciences (Pakistan), Tsinghua University (China), University of South Australia (Australia)

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**Action Web site:**

<http://opticwise.uop.gr/>

**Grant Holder Representative:**

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- **Working Groups** (*list of WGs and names and affiliations of participants*)

**WG1** - Propagation Modelling and Channel Characterization

**WG2** - Physical Layer Algorithm Design and Verification

**WG3** - Networking Protocols

**WG4** - Advanced Photonic Components

Participant	Affiliation	WG1	WG2	WG3	WG4
Erich LEITGEB (Austria)	Graz University of Technology	x	x	x	
Slavisa ALEKSIC** (Austria)	Vienna University of Technology		x	x	
Markus LOESCHNIGG** (Austria)	Graz University of Technology				
Pirmin PEZZEI** (Austria)	Graz University of Technology	x	x		
Paul BRANDL (Austria)	Vienna University of Technology				x
Jurgen VAN ERPS** (Belgium)	Vrije Universiteit Brussel				x
Ioannis KRIKIDIS** (Cyprus)	University of Cyprus		x		
Stefanos ANDREOU** (Cyprus)	University of Cyprus		x		
Vaclav KVICERA (Czech Republic)	Czech Metrology Institute	x			
Otakar WILFERT (Czech Republic)	Brno University of Technology	x	x		
Stanislav ZVANOVEC** (Czech Republic)	Czech Technical University in Prague	x	x		
Ondrej FISER (Czech Republic)	Institute of Atmospheric Physics of Czech Academy	x	x		
Juraj POLIAK** (Czech Republic)	Brno University of Technology	x	x		
Jiří LIBICH** (Czech Republic)	Czech Technical University in Prague	x			
Petr FUKAL** (Czech Republic)	Czech Technical University in Prague	x			
Marcos KATZ (Finland)	University of Oulu			x	
Helal CHOWDURY** (Finland)	University of Oulu			x	

Mohammad-Ali KHALIGHI (France)	Institut Fresnel	x	x		
Guowei YANG** (France)	Institut Fresnel	x	x		
Shihe LONG** (France)	Institut Fresnel	x	x		
Bruno FRACASSO (France)	Telecom Bretagne		x		x
Stephanie SAHUGUEDE*** (France)	University of Limoges		x		
Florian MOLL (Germany)	DLR (German Aerospace Centre)	x	x		
Klaus-Dieter LANGER (Germany)	Fraunhofer Heinrich Hertz Institute		x		x
Liane GROBE*** (Germany)	Fraunhofer Heinrich Hertz Institute		x		x
Mike WOLF (Germany)	Technische Universität Ilmenau		x		
Werner ROSENKRANZ (Germany)	Christian-Albrechts-Universität zu Kiel		x		
Frank DEICKE (Germany)	Fraunhofer Institute		x		
Hubertus HAAN (Germany)	Cassidian Optronics, EADS		x		x
George K. KARAGIANNIDIS (Greece)	Aristotle University of Thessaloniki	x	x		
Anthony C. BOUCOUVALAS (Greece)	University of Peloponnese	x	x		x
Kostas YIANNOPOULOS (Greece)	University of Peloponnese			x	
Periklis CHATZIMISIOS (Greece)	Alexander Technological Educational Institute of Thessaloniki		x	x	
Eszter GERHATNE UDVARY*,** (Hungary)	Budapest University of Technology and Economics		x		x
Istvan FRIGYES (Hungary)	Budapest University of Technology and Economics	x	x		
Gabor FEHER (Hungary)	Budapest University of Technology and Economics		x		
Tamás LENGYEL** (Hungary)	Budapest University of Technology and Economics		x		
Shlomi ARNON (Israel)	Ben Gurion University of the Negev	x	x		
Yehuda LEVIATAN	Technion–Israel Institute of Technology		x		
Ernesto CIARAMELLA (Italy)	Scuola Superiore Sant'Anna	x	x		x
Giorgio Maria TOSI BELEFFI (Italy)	Italian Ministry of Economic Development Sector Communication	x	x		
Frank Silvio MARZANO (Italy)	Sapienza University of Rome	x	x		
Carlo CAPSONI (Italy)	Politecnico di Milano		x		
Valeria CARROZZO*,** (Italy)	Italian Ministry of Economic Development Sector Communication		x		
Andrea ANDO** (Italy)	University of Palermo		x		
Enkelet GJOKA** (Italy)	Sapienza University of Rome	x			
Marian MARCINIAK (Poland)	Kielce University of Technology		x		x
Yevhen YASHCHYSHYN (Poland)	Warsaw University of Technology	x			

Henrique SALGADO (Portugal)	INESC Porto		x		x
Antonio TEIXEIRA (Portugal)	Campus Universitario Santiago		x		
Luis ALVES (Portugal)	Campus Universitario de Santiago	x	x		x
Joao OLIVEIRA** (Portugal)	INESC TEC		x		
Giorgia PARCA** (Portugal)	Instituto de Telecomunicações		x		
Dan SPOREA (Romania)	National Institute for Laser, Plasma and Radiation Physics	x			
Dorin DUDU (Romania)	National Institute for Physics and Nuclear Engineering	x			
Goran DJORDJEVIC (Serbia)	University of Nis		x		
Gorazd KANDUS (Slovenia)	Josef Stefan Institute	x	x		
Aniceto BELMONTE (Spain)	Technical University of Catalonia, BarcelonaTech	x	x		
Pablo ACEDO (Spain)	Universidad Carlos III de Madrid		x		
Ignacio SANTAMARIA (Spain)	University of Cantabria	x	x		
Michal PIORO (Sweden)	Lund University			x	
Yuan Li** (Sweden)	Lund University			x	
Di YUAN (Sweden)	Linköping University		x	x	
Evangelos ANGELAKIS** (Sweden)	Linköping University			x	
Qing HE***	Linköping University			x	
Murat UYSAL (Turkey)	Ozyegin University	x	x	x	
Yahya BAYKAL (Turkey)	Cankaya University	x			
Muammer UYSAL (Turkey)	Omnitek				x
Roger J. GREEN (United Kingdom)	University of Warwick	x			x
Laura JOHNSON***	University of Warwick				
Zabih GHASSEMLOOY (United Kingdom)	Northumbria University	x	x	x	
Joaquin Perez SOLER ** (United Kingdom)	Northumbria University	x	x	x	
Wai Pang NG (United Kingdom)	Northumbria University		x		
Harald HAAS (United Kingdom)	University of Edinburgh	x	x	x	
Dominic O'BRIEN (United Kingdom)	Oxford University	x	x		
Sujan RAJBHANDARI** (United Kingdom)	Oxford University		x		
Jean ARMSTRONG* (Australia)	Monash University	x	x		

\* Indicates female researcher

\*\* Indicates early stage researcher (ESR)

## ***I.B. Management Committee member list***

### **MC Members**

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**Others**

Bank Charges (SWIFT transfer charges)	<b>446,00</b>
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**Action Total : 84.879,50**

**II. Scientific Report** prepared by the Chair of the Management Committee of the Action, describing results achieved during the Action operation in this period, in no more than 3 pages (the report is "cumulative"). All items listed in Sections A, B, and C, below, must be addressed.

Additional documentation such as extended scientific reports, proceedings of workshops, seminars or conferences may be provided separately as an annex to this report, and should be referenced in the report.

### **II.A. Innovative networking**

- Innovative knowledge resulting from COST networking through the Action. (Specific examples of Results vs. Objectives)
- Significant scientific breakthroughs as part of the COST Action. (Specific examples)
- Tangible medium term socio-economic impacts achieved or expected. (Specific examples)
- Spin off of new EC RTD Framework Programme proposals/projects. (List)
- Spin off of new National Programme proposals/projects. (List)

### **II.B. Inter-disciplinary networking**

- Additional knowledge obtained from working with other disciplines within the COST framework. (Specific examples)
- Evaluation of whether the level of inter-disciplinarity is sufficient to potentially provide scientific impacts. (Specific examples)
- Evaluation of whether the level of inter-disciplinarity is sufficient to potentially provide socio-economic impacts. (Specific examples)

### **II.C. New networking**

- Additional new members joining the Action during its life.
- Total number of individual participants involved in the Action work. (Number of participants. Give % of female and of Early Stage Researcher participants)
- Involvement of Early Stage Researchers in the Action, in particular with respect to STSMs, networking activities, and Training Schools. In addition, justification should be provided if less than 4 STSMs were carried out during the year.
- Involvement of researchers from outside of COST Countries. (Number of participants from non-COST Countries approved by the CSO. Give % of such participants from countries with reciprocal agreements. Specify their contribution)
- Advancement and promotion of scientific knowledge through publications and other outreach activities. (Number of publications and other outreach activities that resulted from COST networking through the Action. Complete list should be given in an annex)
- Activities and projects with COST network colleagues.
- The capacity of the Action members to raise research funds.

### **II.D. Self evaluation**

Indicate in no more than 1 page what, in the opinion of the MC, were the main successes, drawbacks (if any) and the key difficulties encountered (if any).

### **III. Previous scientific report(s)**

Part II of past periods' reports are to be found here.

## **II. Scientific Report**

### **II.A. Innovative networking**

The scientific focus of OPTICWISE is to explore and develop novel methods, models, techniques, strategies and tools in infrared, visible, and ultraviolet spectral bands that will facilitate the implementation of state-of-the-art optical wireless communication (OWC) systems for future generations of heterogeneous wireless communication networks. Since the start of the Action (November 2011), the Action participants have been working on different aspects of OWC and produced a total of **24 input documents** (see Annex II) and **207 publications** (see Annex III) with **29 papers as a joint work** of Action participants from different institutions. The current research funding comes from **8 EC projects**, **22 national projects** and some other sources (See Annex I).

In the following, we summarize the major scientific achievements within each Working Group (WG): The first step in OWC system design, which is dealt by **WG1 (Propagation Modelling and Channel Characterization)**, is to develop, evaluate and validate statistical and empirical channel models for indoor and outdoor OWC applications. The WG1 has devoted large efforts on the microphysical and thermodynamic characterization of meteorological constituents (i.e., rain, snow, fog, haze, clouds etc) [2-ID3, P64, P81, P96, P98, P101, P102]. The development of advanced empirical channel models and tools to evaluate and predict the effect of such meteorological phenomena on the outdoor OWC links have been further addressed. In particular, priority has been given to the effect of fog, which is the most impairing meteorological condition for terrestrial OWC links. The WG1 participants [P65, P67, P68, P70, P72] have analysed the possible use of Visibility (V) as well as of Liquid Water Content (LWC) and Particle Surface Area (PSA) as precursors of the amount of path attenuation over a OWC link. Channel modeling is still an open one and more work is envisaged in the next year. Some initial studies have been carried out also on the determination of the most appropriate wavelengths in the infrared to ultraviolet spectral bands to be used for communication applications [P77, P78]. Deployment of different beam shapes and types has been extensively investigated [P41, P43, P189, P190, P191, P192, P197, P198, P199, P201, P202, P203]. To confirm the theoretical findings on propagation modeling and channel characterization, experimental measurements campaigns have been also carried out by various research groups [P45, P74, P102, P103, P106, P110] in different environments and with different set ups [2-ID5, 3-ID8, P53, P95, P98, P103, P105, P106, P108, P110, P111, P112, P114]. Experimental activities are expected to continue through the whole duration of the Action with updated facilities and even more problem-focused experiments.

The **WG2 (Physical Layer Algorithm Design and Verification)** is involved with the development of efficient physical (PHY) layer solutions for OWC systems. The investigation of multiple input multiple output (MIMO) systems has been carried out by various participants [P8, P39, P51, P94, P180, P183] for both indoor and outdoor OWC. MIMO systems involve the use of multiple transmitters and receivers and provide superior performance (in terms of reliability and throughput) over conventional single transmitter/receiver systems. Another promising solution to improve the link reliability particularly for outdoor OWC systems in the presence of atmospheric turbulence is relay-assisted (cooperative transmission). Relay-assisted OWC systems have been investigated in [P5, P7, P9, P13, P154, 3-ID6] and shown to outperform conventional direct (point-to-point) transmission. Some initial results on adaptive OWC transmission [P3, P57, P69, P157] and coded OWC transmission [P32, P100, 2-ID9, 2-ID11] have been obtained and more work is envisaged on these topics within next year. A particular area which WG2 participants have devoted large efforts is hybrid RF/OWC outdoor systems [P6, P40, P42, P64, P83, P95, P109, 2-ID10] in an effort to simultaneously leverage the media and spatial diversities for weather-robust performance. For high-rate indoor OWC, an active research topic has been the development of optical orthogonal frequency division multiplexing (OFDM) [P175, P177, P178, P204, P205, P206, P207] using visible light band. More research efforts are expected on this topic within next year as visible light communication (VLC) has been receiving a growing attention from both academia and industry. Within the WG2, majority of the research efforts have concentrated on intensity modulation and direct detection (IM/DD) systems which are commercially used due to their simplicity and low cost. To address longer term market needs, coherent modulation and detection techniques have been further explored [P6, P23, P24, P57, P58, P60, P61, P62].

The **WG3 (Networking Protocols)** deals with the upper layer issues above the PHY layer. This line of research consists of developing models and algorithms for optimizing outdoor OWC-based networks, encompassing such elements as advanced automatic repeat request (ARQ) algorithms, multiple access techniques, scheduling algorithms, topology control, routing of demand flows, and cross-layer designs. Although such topics have been widely investigated in wireless radio-frequency networks, the relevant literature in the context of OWC is very sparse. Initial results by the WG3 participants on the development of ARQ protocols and joint topology control and routing algorithms can be found in [P6, 184, 2-ID2, 3-ID1]. On the other hand, for indoor OWC systems, performance analysis and optimization of the link-layer protocols in Gb/s infrared links have been addressed in [P116, P117, P118, P119].

The successful implementation of OWC systems and indeed the research activities highlighted in the previous WGs are premised on the availability of suitable and appropriate optoelectronic/optical front-end devices and components. These issues are addressed by the **WG4 (Advanced Photonic Components)**. Some specific objectives tackled by the WG4 include the investigation of optical wavelength selection for terrestrial and indoor applications, with emphasis on the availability of relevant devices and components [P77, P78, P143], the development of multi-array transmitters and receivers [P15, P79, P116, P118, P119, P139, P157, P161, P167], the design and development of highly sensitive optical receiver with optical amplifiers [P36, P134, P144, P160, P170], the integration of the optoelectronic and electronics at substrate levels [ID10, P146], and the investigation of a combination of tracking transmitters and tracking receivers with the potential to maximise the power available at the receiver [ID2, P130, P135, p139, P140]. Design and development of various OWC subsystem/system test-beds at visible, infrared and ultraviolet wavelengths for indoor and outdoor applications have been also carried out by various research groups within the Action [ID7, ID5, P14, P16, P18, P19, P55, P56, P80, P85, P141, P155, P160, P166, P168, P170, P172].

In the long run, the scientific advances within the Action are expected to facilitate the implementation of future generations of OWC systems which we envision as an indispensable part of a future wireless eco-system. This of course requires not only scientific advances, but also acceptance of the OWC technology by stakeholders. So far, OWC's market penetration has been very limited and OWC technology is considered "niche" by many. To better understand the market needs and trends and to understand the roadmap for OWC, we have formed a **SIG on "Techno economics, industrial standards and future trends in OWC (TESEO)"**. This SIG deals with business/market issues related to OWC and has an active participation in international standard bodies activities related to OWC. The first annual report of the SIG TESEO can be found in the Annex V. This report first introduces the major international institutions involved in OWC regulations and standards. Then it provides market drivers for OWC based on the expert inputs from the industry and polls conducted within the Action. It also reports the current records on achievable data rates in OWC for various applications. SIG TESEO will continue its efforts in close contact and consultation with the industry, other COST Actions, EU Projects (FP8, Horizon2020) and Standardization Bodies.

Through this SIG, we have also established connections with the recently launched Li-Fi Consortium (<http://www.lificonsortium.org/>), which is a non-profit organization to promote OWC with a particular focus on visible light communications. OPTICWISE was accepted to be a **member of Li-Fi Consortium** and represented by the Action Chair Prof Uysal and MC Member Prof Alves. Prof Uysal gave an invited talk entitled "COST Action OPTICWISE: Shaping the Future of Optical Wireless Communications" at online Li-Fi forum in March 2013.

## ***II.B. Inter-disciplinary networking***

To cover all aspects of the planned scientific activities, the Action builds upon four WGs. Most of the Action participants are involved in more than one WG, which is promising for the adopted interdisciplinary approach. The membership of application-focused SIGs is from different WGs. Therefore, the SIGs provide an excellent platform to bring together researchers with the complementary research experience and expertise. We currently have two application-focused SIGs, namely "**Underwater OWC**" and another on "**Visible Light Communications**" approved at the MC2 Meeting in Istanbul. The scope and mandate of these SIGs can be found, respectively, in

Annex V and Annex VI.

To avoid duplication as well as to motivate interdisciplinary collaboration among the Action participants, a **researcher information database** was put together. This database available at the Action website contains information on research activities and research resources (both hardware and software) of the participants. Easy access to such information was received well by the Action participants who can use this database to identify partners in EU projects or hosts in their STSM applications.

Relationships with other COST Actions and EU projects have been established to motivate collaborations and fertilize interdisciplinary research. Particularly, our Action has been in close relation with the recently ended **IC0802**. In fact, most members of the WG3 (Channel modeling for terrestrial free-space optical systems and airborne terminals) in IC0802 are now active participants of our Action. The MC members who are also affiliated with other Actions were identified and assigned as liaisons to the relevant Actions. Specifically, Profs. Dan Sporea and Marian Marciniak act as liaisons to the Actions **TD1001**, **IC1004**, and **MP1204**. Furthermore, we have established contacts with **IC1104** through Prof. Uysal, and **IC0905** through Dr. Tosi Beleffi, for possible collaborations and exchanges of ideas. Last, but not least, we initiated contact with the **FP7 project ISLA** (Integrated disruptive componentS for 2 µm fibre Lasers, <http://www.isla-project.eu/>). Dr. Peter Shardlow, a partner of the ISLA project, was invited to our MC meeting in Prague (April 25-26) and delivered a talk. Such a contact is particularly valuable for WG4 which is involved in the investigation of optical wavelength selection for terrestrial OWC applications, with emphasis on the identification of relevant components, devices and associated trade-offs.

### **II.C. New networking**

As of May 2013, 21 COST countries signed the MoU. 77 participants were so far actively involved in the Action work. This includes the number of MC members, MC substitute members or invited experts (who participated, at least, one MC meeting), and trainees/trainers in our training school. With the external participants for the workshop (7) and audience from the local organizing institutions (8 at MCM2 and 10 at MCM3), this reaches to a total of 102 participants.

Comment [ZG1]: ??

Among the 77 active participants, there are 28 early stage researchers (ESRs) -including trainees- and 6 female researchers indicating a significant increase from the respective number of early stage/female researchers in the first report. It should be further emphasized that Vice-Chair positions in WGs were exclusively allocated for the candidates among ESRs. WG4 is currently vice-chaired by a female researcher.

Within the first budget year, 5 STSMs were carried out. In the selection of STSMs, the priority was given to ESRs and 4 out of 5 STSMs were accomplished by the ESRs. The first training school was held at the University of Northumbria, Newcastle, UK. All 11 trainees were ESRs.

There are currently 5 participants from non-COST Countries approved by the CSO. Their geographical locations are quite diverse and include Australia, China, Pakistan, and South Korea. Some other institutions from Japan, Canada, Taiwan and USA further indicated interest in joining the Action's activities. It is expected that their paperwork will be completed and become official participants within this year.

The Action participants produced a total of 207 publications 29 of which are as a result of COST networking through the Action (See Annex II). The participants currently hold research funding from a total of 33 projects including 8 EC projects and 22 national projects (See Annex I).

In terms of dissemination activities, we have activated the website of the Action as well as OPTICWISE accounts in social networks (Facebook, LinkedIn, Twitter). A leaflet which provides general information and overall activities of OPTICWISE was prepared and distributed by both e-mail and postal mail. The Action also publishes a semi-annual newsletter highlighting the latest achievements and public deliverables of the Action. The first issue was published in Fall 2012. Another outreach activity was our first workshop which was held in conjunction with the MC3 meeting in October 2012. It was highly successful and was able to attract participants outside the Action. In fact, 10 out of the 21 presented papers belong to researchers outside the Action.

## ***II.D. Self evaluation***

### ***Previous scientific report(s)***

**The following is our first scientific report which covers the period of November 2011 – April 2012.**

The period covered by this report (November 2011 – April 2012) corresponds to the start of the scientific activities of the COST IC1101 Action. The kick-off meeting was held in Brussels on November 08, 2011. The first Management Committee (MC1) Meeting took place on March 19-21 at Ozyegin University in Istanbul, Turkey. This two and half days event represented the first opportunity to gather all interested parties for technical discussions and to set up the Working Groups (WGs) and the Special Interest Groups (SIGs) in line with the MoU.

### ***II.A. Innovative networking***

COST Action IC1101 (OPTICWISE) aims to increase the scientific understanding and technical knowledge of the emerging field of optical wireless communication (OWC) by exploring and developing novel methods, models, techniques, strategies and tools in infrared, visible and ultraviolet spectral bands that will facilitate the implementation of future generations of OWC systems. The innovative approach required to enable radical advances in OWC will only be possible through the integration of expertise and capabilities in diverse areas of research spanning from characterization of propagation media to modelling, design and development of devices, components, algorithms/protocols and systems. During the MC1 meeting, all participants were requested to present an overview of their research activities and R&D capabilities. The scientific expertise of the Action participants were identified to cover all aspects of the planned scientific activities within the Action. WG meetings co-located with the MC1 meeting further provided a platform for the participants to exchange ideas on research topics of each WG in a more focused manner and discuss future directions of the field.

At the MC1 meeting, following technical presentations from colleagues on Underwater OWC and Visible Light Communications and in-depth discussion, it was agreed that it would be beneficial to establish two new SIGs; one on “Underwater OWC” and another on “Visible Light Communications”. The SIGs will be focusing on the applications of OWC technology and will be drawing members from all four WGs.

To avoid duplication, and to increase collaboration among Action participants, as well as to effectively and fully utilise research resources within the community it was decided by the MC that a common database will be put together prior to the next MC meeting. The database will contain information on research activities and research resources (both hardware and software) for all partners, and will be put on the Action website for all to see.

Besides enabling scientific advances in the emerging field of OWC, OPTICWISE aims to serve as an internationally recognized reference point through capacity building of the OWC stakeholders. For this purpose, a SIG on “Techno-Economics, Industrial Standards and Future Trends in OWC (TESEO)” was formed. This SIG focuses on the leading trends in the emerging OWC applications and educating and influencing decision makers at national and international levels through the participation in standards bodies and international forums. Within this SIG, MC members (Dr. Marian Marciniak, Dr. Vaclav Kvicera, Prof. Roger Green, Prof. Anthony C. Boucouvalas) were identified to liaison with major standardization bodies and global forums such as ITU, URSI, and IrDA.

At the Optical Fiber Conference (OFC) held in Los Angeles during March 4-8 2012, SIG Vice Chair Dr. Klaus Dieter Langer gave a talk on OPTICWISE and SIG-TESEO to a large audience as a part of his invited lecture. Through this SIG, we also established connections with the recently launched

Li-Fi Consortium (<http://www.lificonsortium.org/>), which is a non-profit organization to promote OWC with a particular focus on visible light communications. Li-Fi representative Dr. Frank Deicke gave a talk entitled “Li-Fi Consortium and Li-Fi Eco-System” at the MC1 meeting. It was decided by the MC that OPTICWISE will apply for a membership of the Li-Fi Consortium and pursue joint activities whenever possible.

## ***II.B. Inter-disciplinary networking***

Implementation of the scientific tasks defined in the Action MoU requires to synergize the interdisciplinary scientific expertise of European researchers in diverse fields such as the electromagnetic propagation theory, atmospheric physics, meteorology, information/communication theory, networking, communication systems, photonic components, devices and systems. It was discussed during the MC1 meeting that “horizontal” and “vertical” organizational structure of the Action implemented through the *topic-focused* WGs and *application-focused* SIGs would be a key to maximize the inter-disciplinary activities within the Action.

To cover all aspects of the planned scientific activities, we have identified four topical WGs that complement one another. These WGs are: **WG1 - Propagation Modelling and Channel Characterization**; **WG2 - Physical Layer Algorithm Design and Verification**; **WG3 - Networking Protocols**; and **WG4 - Advanced Photonic Components**. During the MC1 meeting, most of the Action participants indicated interest in involving in more than one WG, which is promising for the adopted interdisciplinary approach.

The membership of application-focused SIGs is from different WGs. Therefore, the SIGs provide an excellent platform to bring together researchers with the complementary research experience and expertise. At MC1 meeting, two new SIGs were formed. The philosophy of forming more SIGs will be encouraged in the light of technical trends, progress and new developments.

Collaborations with other COST Actions are further planned for interdisciplinary research. MC members who are also affiliated with other Actions were identified and will act as liaisons to the relevant Actions. These include **IC0802** (Propagation tools and data for integrated Telecommunication, Navigation and Earth Observation systems), **IC0902** (Cognitive Radio and Networking for Cooperative Coexistence of Heterogeneous Wireless Networks), **IC1004** (Cooperative Radio Communications for Green Smart Environments), and **TD1001** (Novel and Reliable Optical Fibre Sensor Systems for Future Security and Safety Applications). In line with these efforts, the Action Chair Dr. Murat Uysal gave a plenary talk entitled “COST Action OPTICWISE: Shaping the Future of Optical Wireless Communications” at the 7<sup>th</sup> MC meeting of IC0802 in April 2012.

It was also decided to establish contacts with **IC1104** (Random Network Coding and Designs over GF(q)), **IC0906** (Wireless Networking for Moving Objects) and **IC0905** (Techno-Economic Regulatory Framework for Radio Spectrum Access for Cognitive Radio/Software Defined Radio) for possible collaborations and exchanges of ideas etc.

## ***II.C. New networking***

As of April 2012, 19 COST countries signed the MoU. 40 participants<sup>1</sup> were so far involved in the Action work. Among those, there are 5 early stage researchers (ESRs) and 1 female researcher. Vice-Chair positions in WGs were exclusively allocated for candidates among ESRs. WG4 is currently vice-chaired by a female researcher.

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<sup>1</sup> At the stage of proposal writing, there were 55 researchers who indicated interest and provided input. Due to COST program’s limitations on the number of MC members per country, not all of them were able to participate in the Action. In some countries such as UK, it was decided that participants will serve on the MC on a rotating basis.

Within the first budget year, there are 8 STSMs planned. So far, one STSM application was received and unanimously approved by the Steering Committee.

Ten institutions from outside of COST Countries indicated interest in joining the Action's activities. Their geographical locations are quite diverse and include Armenia, Australia, Canada, China, Japan, Pakistan, South Korea, Taiwan, and USA. They were asked to fill out the required paperwork. It is expected that their paperwork will be ready by June-July for MC approval.

In terms of dissemination activities, the website of the Action became active in February 2012. In an effort to increase public awareness and attract young researchers, it was decided at the MC1 meeting that social networking tools such as Facebook, LinkedIn, Twitter, Google Groups etc. should be effectively used by the Action. These tools will be activated by the next MC meeting. A leaflet which provides general information and overall activities of OPTICWISE is currently under preparation. It was also decided by the MC that a semi-annual newsletter will be published highlighting the latest achievements and public deliverables of the Action. Dr. Florian Moll agreed to serve as the Editor of this newsletter.

#### **II.D. Self evaluation**

### **Annex I**

#### **OWC-related EC RTD Framework Programme Proposals/Projects by Action Participants (since the start of the Action)**

	<b>Action Participant(s)</b>	<b>Project/Proposal Name, Budget, Duration and Other Details (if applicable)</b>
<b>1</b>	<b>L. N. Alves</b>	<b>LITES (CIP-ICT-PSP-2008-2/238916)</b> <i>Led-based intelligent street lighting for energy savings</i> , 260,000 Euro (project global budget: 2,560,000 Euro), 2009 -2012
<b>2</b>	<b>L. N. Alves</b>	<b>PUDeM-SensNet (FP7-ICT-2013-X, 613144, CP-FP-INFSO)</b> <i>New Communication Paradigms for Ultra-Dense Multi-mode Sensor Networks</i> . Project proposal submitted to the FP7-ICT-2013-X (FET-OPEN, Xtrack) January 2013. Global budget requested is 1,660,000 Euro for a duration of 3 years.
	<b>J. Van Erps</b>	<b>ACTMOST (Access To Micro-Optics Expertise, Services and Technologies)</b> , 481,500 Euro (project global budget 1,2000,000 Euro), 2010-2013
<b>3</b>	<b>Z. Ghassemlooy</b>	<b>EU FP7, ERASMUS MUNDUS (372242-1-2012-1-UK-ERA MUNDUS-EMA21)</b> <i>cLink Project - centre of excellence for Learning, Innovation, Networking and Knowledge</i> , 750,000 Euro (project global budget 2,500,000 Euro), 2012-2016

4	Z. Ghassemlooy	<b>EU TEMPUS-JPGR 0 517501-TEMPUS-1-2011-1-FR-)</b> <i>Information Management System in Higher Education Institutions in Algeria for their Bachelor, Master and Doctoral Programme, 87,000 Euro, 2011-2014</i>
5	M. Ali Khalighi	<b>EU FP7 Marie Curie Initial Training Network</b> <i>SENSEnet (International Sensor Development Network), 120,000 Euro, 2009-2012</i>
6	M. Uysal	<b>EU FP7 Marie Curie International Reintegration Grant</b> <i>Free-Space Optical Systems for Next Generation Communication Networks, 100,000 Euro, 2011-2014</i>
7	D. Yuan and V. Angelakis	<b>EU-FP7 MC- IRSES (318906)</b> DETERMINE: Designing Future Optical Wireless Communication Networks, 2013- 2017
8	D. Yuan and V. Angelakis	<b>EU-FP7 MC- IAPP (324515)</b> MESH-WISE: Self-organising MESH Networking with Heterogeneous Wireless Access, 2013- 2017

**OWC-related National Programme Proposals/Projects by Action Participants (since the start of the Action)**

	Action Participant(s)	Project/Proposal Name, Budget, Duration and Other Details (if applicable)
1	S. Aleksic	HOME-ICT: ICT technologies in the domestic sector, 200,000 Euro, 2010 – 2013, Partners: Austrian Energy Agency and Vienna University of Technology
2	S. Aleksic	QKD-Telco: Practical Quantum Key Distribution over TELeCOM-Infrastructures, 507,900 Euro, 2012 – 2015, Partners: Austrian Institute of Technology, Vienna University of Technology and Sitexs-Databusiness IT-Solutions GmbH
3	L. N. Alves	Energy Efficient Current-mode techniques for free-space Optical front-end receivers, 50,000 Euro, March 2010 - October 2012
4	A. Belmonte	Experimental evaluation of complex optical adaptive arrays in free-space coherent laser communications, 145,200 Euro, Spanish Department of Science and Innovation MICINN.
5	A. Belmonte	Atmospheric compensation experiments on advanced free-space optical communication systems, 169,400 Euro, Spanish Department of Science and Innovation MICINN
6	A. Belmonte	Novel detection system for coherent free-space optical communications, 49,859 Euro, ESA/ESTEC

7	<b>A. Belmonte</b>	Influence of the atmospheric channel on IOD performance characteristics, 21,539 Euro, RUAG Space
8	<b>J. Van Erps</b>	APPLIE4MOS "Advanced Polymer Prototyping Line for Micro- and Micro-Optical Systems", 1.686.801 euro Duration: 2010-2015
9	<b>I. Frigyes J. Bitó</b>	MILLIPROP, 15,000 Euro/year, 2009-2012
10	<b>Z. Ghassemlooy</b>	UK HIEF Project Hybrid RF-FSO system, 15,000 Euro, 2012
11	<b>Z. Ghassemlooy</b>	Dual Propose Antenna Dish for FSO and RF, 15,000 Euro, 2012-2013
12	<b>Z. Ghassemlooy</b>	Secure Mobile Visible Light Near Field Communications, 7,000 Euro, 2012
13	<b>R. J. Green</b>	Underwater optical communications, Collaborative Award in Science and Engineering funded by the Engineering and Physical Science Research Council (UK), 120,000 Euro, 2010-2015
14	<b>R. J. Green</b>	Blind navigation, Warwick alumnus fund, 70,000 Euro, 2012-2015.
15	<b>G. Kandus T. Javornik</b>	Telecommunication systems, 30,000 Euro/year, 2009-2014
16	<b>V. Kvicera</b>	Effect of Propagation Impairments on Error Performance of Future Broadband Terrestrial Wireless Systems, 67,000 Euro, 2012
17	<b>F.S. Marzano G. Tosi Beleffi V. Carrozzo</b>	JLabAP-FSO, 23,000 Euro, 2012
18	<b>Y. Yashchyshyn</b>	New Generation of Photonic Antennas for Radio over Fiber Transmission Systems, 160,000 Euro, 2010 – 2012
19	<b>M. Uysal</b>	Physical and Upper Layer Solutions for Next Generation Optical Wireless Communications, 108,179 Euro, 2012 - 2015, supported by The Scientific and Technological Research Council of Turkey (TUBITAK) as a COST project 2515
20	<b>M. Uysal</b>	A Green Approach for Wireless Access: Visible Light Communication, 28,000 Euro, 2013
21	<b>S. Zvanovec</b>	Advanced Techniques of Component Design for Sensor Systems, 144,000 Euro, 2012-2013
22	<b>S. Zvanovec</b>	Research of Ambient Influences on Novel Broadband Optical Wireless Systems (RAINBOWS), 65,000 Euro, 2012-15, supported by The Ministry of Education, Youth and Sports (MEYS) as a COST project LD12058

**OWC-related Other Proposals/Projects by Action Participants (since the start of the Action**

	Action Participant	Project/Proposal Name, Budget, Duration and Other Details (if applicable)
1	J. Van Erps	Survey on next-generation optical interconnect architectures, Bilateral Agreement WDGO988 - Photonics Electronics Technology Research Association PETRA, 30,000 euro 2012-2015
2	M. Uysal	Advanced Transmission Techniques for Terrestrial Optical Wireless Communications, 1,017,640 US\$, Qatar National Research Fund, 2013-2015
3	M. Uysal	Visible Light Communications, 1,011,226 US\$, Qatar National Research Fund, 2013-2015
4	M. Uysal Z. Ghassemlooy	Visible Light Communications for Intelligent Transport Systems. Project proposal submitted to Qatar National Research Fund. Requested budget is 1,046,758 US\$

## Annex II Input Documents

**2<sup>nd</sup> Management Committee Meeting**, Istanbul, Turkey, March 19-21, 2012

	Author(s)	Title of the Input Document
2-ID1	L. N. Alves	Visible Light Communications in Public Lighting Systems
2-ID2	Y. Baykal	Evaluation of average intensity, scintillations and BER in all turbulence strengths for arbitrary incidence and different atmospheric power spectra
2-ID3	C. Capsoni R. Nebuloni L. Luini	Earth-space optical wireless communications: the challenge of the atmosphere
2-ID4	M. A. Khalighi	Propagation Modelling and Channel Characterization
2-ID5	F. Moll	Channel Characterization and modelling for long distance free-space optical links
2-ID6	S. Zvanovec	Analyses of and Measurements of Optical Wireless Systems at the Czech Technical University in Prague
2-ID7	I. Frigyes	RoFSO (Radio over Free Space Optics)
2-ID8	Z. Ghassemlooy H. Le Minh S. Rajbhandari	Development of Visible Light Communication Systems

	<b>J. P. Soler P. Haigh A. Burton</b>	
<b>2-ID9</b>	<b>M. A. Khalighi</b>	Physical Layer Algorithm Design and Verification
<b>2-ID10</b>	<b>Y. Yashchyshyn</b>	Hybrid RF/optic links for wireless communication systems
<b>2-ID11</b>	<b>T. Javornik G. Kandus</b>	Advanced modulation and coding scheme examples for FSO communications
<b>2-ID12</b>	<b>D. Yuan V. Angelakis M. Pióro</b>	Network optimization models& algorithms for OWC
<b>2-ID13</b>	<b>H. Al Hajjar B. Fracasso D. Leroux</b>	Fibre-distributed indoor high bitrate optical wireless system
<b>2-ID14</b>	<b>J. Van Erps</b>	Brussels Photonics Team: Services available for the IC1101 Consortium

**3<sup>rd</sup> Management Committee Meeting, Pisa, Italy, October 22-24, 2012**

	<b>Author(s)</b>	<b>Title of the Input Document</b>
<b>3-ID1</b>	<b>V. Angelakis D. Yuan</b>	The FP7-PEOPLE-2012-IRSES DETERMINE Project Activities within WG3
<b>3-ID2</b>	<b>P. Brandl H. Zimmermann</b>	Circuit Engineering in the field of OWC at TU Vienna
<b>3-ID3</b>	<b>L. M. Pessoa H. M. Salgado</b>	Underwater optical wireless communications
<b>3-ID4</b>	<b>Y. Yashchyshyn A. Urzędowska K. Godziszewski</b>	Radio over Fibre link for field distribution measurements
<b>3-ID5</b>	<b>A. M. Khalid G. Cossu R. Corsini E. Ciaramella</b>	Gigabit-Class Visible Light Communication Systems Based on Illumination LEDs
<b>3-ID6</b>	<b>M. Uysal M. A. Kashani</b>	Performance Analysis and Optimization of Relay-Assisted FSO Systems
<b>3-ID7</b>	<b>G. Fehér G. Fekete E. Udvary</b>	Different approaches to develop an indoor visible light communication link
<b>3-ID8</b>	<b>V. Kvicera</b>	Experimental optical/radio/meteorological research at the Czech

	<b>M. Grabner</b>	Metrology Institute in Prague.
3-ID9	<b>M. Petkovic G. T. Djordjevic D. Denic</b>	BER Performance of QAM FSO Communication System
3-ID10	<b>K.-D. Langer L. Grobe</b>	Recent Results and Emerging Solutions in Optical Wireless Indoor Communications

### Annex III

#### Publications by the Action Participants (since the start of the Action)

**Note 1:** The names of Action participants are in bold.

**Note 2:** "Joint Work" in the third column means joint work of Action participants from different institutions.

**Note 3:** J/C/B/BC/O in the fourth column, respectively, indicate "Journal Paper", "Conference Paper", "Book", "Book Chapter" and "Others (i.e., Technical Report, etc)"

	<b>Authors and Publication Title</b>	<b>Joint Work</b>	<b>J/C/B/BC/O</b>
P1	<b>S. Arnon</b> , J. R. Barry, <b>G. K. Karagiannidis</b> , R. Schober, and <b>M. Uysal</b> (Eds.), <i>Advanced Optical Wireless Communication</i> , Cambridge University Press, July 2012.	Y	B
P2	<b>Ghassemlooy, Z.</b> , Popoola, W. O., and <b>Rajbhandari, S.</b> : <i>Optical Wireless Communications – System and Channel Modelling with Matlab</i> , CRC publisher, USA, August 2012, ISBN: 978-4398-5188-3.		B
P3	M. Karimi and <b>M. Uysal</b> , "Novel Adaptive Transmission Algorithms for Free-Space Optical Links", accepted for publication in <i>IEEE Transactions on Communications</i> .		J
P4	M. A. Kashani, <b>M. Uysal</b> and M. Safari, "Optimal Relay Placement and Diversity Analysis of Relay-Assisted Free-Space Optical Communication Systems", <i>IEEE/OSA Journal of Optical Communications and Networking</i> , vol. 5, no. 1, p. 37-47, January 2013.		J
P5	M. A. Kashani, M. M. Rad, M. Safari, and <b>M. Uysal</b> , "All-Optical Amplify-And-Forward Relaying System for Atmospheric Channels", <i>IEEE Communications Letters</i> , vol. 16, no. 10, p. 1684-1687, October 2012.		J
P6	S. M. Aghajanzadeh and <b>M. Uysal</b> , "Information Theoretic Analysis of Hybrid ARQ Protocols in Coherent Free-Space Optical Systems", <i>IEEE Transactions on Communications</i> , vol. 60, no. 5, p.1432-1442, May 2012.		J
P7	M. Safari, M. M. Rad, and <b>M. Uysal</b> , "Multi-Hop Relaying over the		J

	Atmospheric Poisson Channel: Outage Analysis and Optimization", <i>IEEE Transactions on Communications</i> , vol. 60, no. 3, p. 817-829, March 2012.		
P8	H. Kazemi and <b>M. Uysal</b> , "Performance Analysis of MIMO Free-Space Optical Communication Systems with Selection Combining", <i>IEEE 21st Signal Processing, Communication and Applications Conference (SIU)</i> , April 2013		C
P9	S. M. Aghajanzadeh and <b>M. Uysal</b> , "Outage Performance and DMT Analysis of DF Parallel Relaying in FSO IM/DD Communications", <i>IEEE VTC-Fall</i> , Quebec City, Quebec, Canada, September 2012.		C
P10	X. Tang, <b>Z. Ghassemlooy</b> , <b>S. Rajbhandari</b> , W. O. Popoola, <b>M. Uysal</b> , and D. Wu, "Experimental demonstration of polarisation shift keying in the free space optical turbulence channel", <i>IEEE International Workshop on Optical Wireless Communications</i> (in conjunction with the IEEE ICC 2012), Beijing, China, August 2012.	Y	C
P11	I. E. Lee, <b>Z. Ghassemlooy</b> , <b>W. P. Ng</b> , and <b>M. Uysal</b> , "Performance analysis of free space optical links over turbulence and misalignment induced fading channels", <i>8th IEEE/IET International Symposium on Communication Systems, Networks and Digital Signal Processing (CSNDSP)</i> , Poznan, Poland, July 2012.	Y	C
P12	M. A. Kashani, M. Safari, and <b>M. Uysal</b> , "Optimal Relay Placement in Cooperative Free-Space Optical Communication Systems", <i>IEEE WCNC'12</i> , Paris, France, April 2012.		C
P13	M. A. Kashani and <b>M. Uysal</b> , "Outage Performance of FSO Multi-Hop Parallel Relaying (in Turkish)", <i>IEEE 18th Signal Processing, Communication and Applications Conference (SIU'12)</i> , Mugla, Turkey, April 2012.		C
P14	<b>Ghassemlooy, Z.</b> , Le Minh, H., Haigh, P. A., and Burton, A.: "Development of visible light communications: emerging technology and integration aspects", Invited Paper, Optics and Photonics Taiwan International Conference (OPTIC) 2012, Taipei, Taiwan, 6-8 Dec. 2012.		C
P15	D. Wu, <b>Z. Ghassemlooy</b> , <b>S. Rajbhandari</b> , H. Le Minh and <b>A. C. Boucouvalas</b> : "Improvement of Transmission Bandwidth for Indoor Optical Wireless Communication Systems Using an Elliptical Lambertian Beam", in <i>Photonics Technology Letters</i> , IEEE, vol.25, no.2, pp.107-110, Jan.15, 2013.	Y	J
P16	<b>Ghassemlooy, Z.</b> : "OLED-based visible light communications", Photonics Society Summer Topical Meeting Series, 2012 IEEE, Digital Object Identifier: 10.1109/PHOSST.2012.6280746, Publication Year: 2012, Page(s): 102 – 104, 2012. Invited paper		C
P17	Haigh, P.; <b>Ghassemlooy, Z.</b> ; Le Minh, H.; <b>Rajbhandari, S.</b> ; Arca, F.; Tedde, S.; Hayden, O.; Papakonstantinou, I.: "Exploiting equalization techniques for improving data rates in organic optoelectronic devices for visible light communications", <i>Lightwave Technology, Journal of</i> , Digital Object Identifier: 10.1109/JLT.2012.2210028, Publication Year: 2012, Page(s): 1 (In print)		J
P18	Haigh, P. A., Son, T. T., Bentley, E., <b>Ghassemlooy, Z.</b> , Le Minh, H. and Chao, L., "Development of a Visible Light Communications System for Optical Wireless Local Area Networks," in <i>IEEE Computing, Communications and Applications Conference (ComComAp)</i> , 2012, 2012, pp. 351-355.		C
P19	Jang, H. J., Choi, J. H., <b>Ghassemlooy, Z.</b> , and Lee, C. G.: "PWM-based PPM format for dimming control in visible light communication system", <i>IEEE, IET 8th International Symposium on Communication Systems, Networks and Digital Signal Processing</i> , Poznan, Poland, 18-20 July 2012.		C
P20	Le Minh, H., <b>Ghassemlooy, Z.</b> , Burton, A., and Haigh, P. A., "Equalization for Organic Light Emitting Diodes in Visible Light Communications," <i>IEEE Globecom Houston</i> , Texas, USA: IEEE, 2011.		C

P21	<b>Ghassemlooy, Z.</b> , Le Minh, H., <b>Rajbhandari, S.</b> , <b>Perez, J.</b> , and Ijaz, M., "Performance Analysis of Ethernet/Fast-Ethernet Free Space Optical Communications in a Controlled Weak Turbulence Condition", Journal of Lightwave Technology, Vol. 30, No. 13, pp. 2188 - 2194, 2012.		J
P22	<b>Ghassemlooy, Z.</b> , Tang, X., and <b>Rajbhandari, S.</b> , "Experimental Investigation of Polarization Modulated Free Space Optical Communication with Direct Detection in a Turbulence Channel", IET Communications, 2012		J
P23	Tang, X., <b>Ghassemlooy, Z.</b> , Rajbhandari, S., Popoola, W. O., and Lee, C. G.: 'Coherent optical binary polarization shift keying heterodyne system in the free space optical turbulence channel', IET Microwaves, Antennas and Propagation, (5), 9, 1031-1038, ISSN 1751-8725, June 2011.		J
P24	Tang, X., <b>Ghassemlooy, Z.</b> , Rajbhandari, S., Popoola, W. O., and Lee, C. G., "Coherent Polarization Shift Keying Modulated Free Space Optical Links Over a Gamma-Gamma Turbulence Channel", Am. J. Eng. Applied Sci., Vol. 4, pp. 520-530, 2011.		J
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#### **Annex IV**

Report 1 of SIG TESEO

#### **Annex V**

SIG on Underwater Optical Wireless Communications

#### **Annex VI**

SIG on Visible Light Communications