

## Editor's Note

The COST Action OPTICWISE is coming to an end, however the OPTICWISE Network will continue! The final workshop is over but the connections and friendships will stay. This Action was an excellent impulse for joint Optical Wireless Communications research in Europe and worldwide. Many future initiatives will benefit from the produced knowledge and research network. Enjoy the last newsletter and be sure that OPTICWISE will appear again in other contexts.

*Florian Moll, Editor of the Newsletter*

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## OPTICWISE Grand Finale

COST IC1101 Action OPTICWISE participants came together last time in Istanbul to hold the final Management Committee (MC) Meeting. A number of parallel Action events took place during September 7-10, 2015 to mark the end of this highly successful Action. The highlight was the fourth edition of International Workshop on Optical Wireless Communication (IWOW), launched by OPTICWISE in 2011 and held every year since then. This year, it attracted about 100 international participants. The keynote speeches were delivered by Prof. Dr. Mohamed-Slim Alouini of King Abdullah University of Science and Technology and Prof. Dr. Alan Willner of the University of Southern California. The rich technical program included four oral and two poster sessions featuring 28 research contributions on a wide range of topics in optical wireless communication. Full details are covered on Page 2 of the newsletter.



Participants of 4<sup>th</sup> IWOW in front of Özyegin University. Along with the MC meeting, the Working Groups (WGs) held their meetings. These meetings provided an opportunity to discuss in depth the Action's scientific

achievements over the last four years and the future research trends ahead. They also featured four invited speakers discussing various applications of OWC ranging from airborne communications to vehicular networking. The talks topics were *Free-Space Optical Links for Airborne Communication Networks* by Dr. Kai-Daniel Büchter of Bauhaus Luftfahrt e.V., *VLC research at ULPGC: Applications for a Smart Tourism Destination* by Prof. Dr. Rafael Pérez Jiménez of Universidad de Las Palmas de Gran Canaria, *Car-Centric View of Networking* by Dr. Onur Altintas of Toyota InfoTechnology Center and *Beyond Illumination with LEDs: Sensing, Communication and Control* by Dr. Ashish Pandharipande of Philips Research.



Registration for 4<sup>th</sup> IWOW and coffee break between sessions.

In parallel to the MC and WG meetings, the fourth edition of Action Training School was held over September 7-10, 2015. The comprehensive program featured a large number of lectures at different levels geared for attendees ranging from senior undergraduate students to post-doctoral researchers. The lectures in first two days mainly covered the fundamentals of free-space optical (FSO) communication and visible light communication (VLC) while the last two days focused on advanced research topics. The trainees who are new to the area have found a unique opportunity to get introduced to the exciting world of optical wireless



communication while more experienced trainees have enjoyed lectures on advanced topics delivered by world renowned researchers.

## IWOW: A Success to Continue

In the first year of the Action, OPTICWISE launched the International Workshop on Optical Wireless Communication (IWOW) as an annual forum to bring together European researchers working on different aspects of optical wireless communication (OWC). Over the four years, it has grown significant attention from OWC researchers all over the world. The Action came to an end, but the OPTICWISE MC decided to continue the organization of IWOW as an independent event.

The fourth edition of IWOW was held on September 7-8, 2015. Its technical program included keynote speeches from world renowned researchers, four oral and two poster sessions featuring 28 research contributions and demonstrations of latest VLC and FSO prototypes from Action participants. The full program can be found below.

## IWOW 2015 Technical Program



### IWOW 2015

4th International Workshop on Optical Wireless Communication  
07-08 September 2015, Özyeğin University, İstanbul, Turkey



**Keynote Speech 1:** Addressing Spectrum Scarcity through Optical Wireless Communications by Prof. Dr. Mohamed-Slim Alouini, King Abdullah University of Science and Technology (KAUST).

Rapid increase in the use of wireless services over the last two decades has led to the problem of the radio-frequency (RF) spectrum exhaustion. More specifically, due to the RF spectrum scarcity, additional RF bandwidth allocation, as utilized in the recent past, is not anymore a viable solution to fulfill the demand for more wireless applications and higher data rates. The talk goes first over the potential offered by optical wireless communications to relieve spectrum scarcity. It then summarizes some of the challenges that need to be surpassed before such kind of systems can be massively deployed. Finally the talk offers an overview of some of the recent results in the area of the performance analysis of optical wireless communication systems.



**Keynote Speech 2:** High-Capacity Free-Space Optical Communications Using Multiplexing of Multiple Orbital-Angular-Momentum Modes by Prof. Dr. Alan Willner, University of Southern California.

The ability to multiplex multiple, spatially overlapping data-carrying modes over the same physical medium represents the potential for increasing system capacity and spectral efficiency. Generating different amounts of orbital-angular-momentum (OAM) on different optical beams has emerged as a technique for such mode multiplexing. Each OAM beam is orthogonal and can be efficiently multiplexed and demultiplexed, and OAM is compatible with other forms of multiplexing (e.g., polarization multiplexing and WDM). This presentation explores the achievements of and challenges to OAM-based free-space optical communication systems, including transmission, turbulence compensation, link design, and switching.

### IWOW Session 1 - Visible Light Communications

*Performance of Carrier-less Amplitude and Phase Modulation with Frequency Domain Equalization for Indoor Visible Light Communications* - by S. Long et al.

*Multi-band Carrier-less Amplitude and Phase Modulation with Decision Feedback Equalization for Bandlimited VLC systems* - by K. Werfli et al.

*Impact of Receiver Orientation and Mobility on Visible Light Communication Link Performance* - by C. Le Bas et al.

*Optical OFDM with Index Modulation for Visible Light Communication* - by E. Basar and E. Panayirci

### IWOW Session 2 - Optical Wireless Communications for Underwater and Space Applications

*Modeling of High-capacity Aeronautical Communication Networks with Free-space Optical links* - by K. D. Büchter

*Experimental characterization of intensity scintillation in the LEO downlink* - by F. Moll

*Clear-air Turbulence Effects Modeling on Terrestrial and Satellite Free-Space Optical Channels* - by F. Marzano et al.

*On the BER of Multiple-Input Multiple-Output Underwater Wireless Optical Communication Systems* - by M. V. Jamali and J. Salehi

*Effects of Focused and Collimated Laser Beams on the Performance of Underwater Wireless Optical Communication Links* - by A. Keskin et al.

### IWOW Session 3 - Free-Space Optical Communications

*Free-Space Optical Communications with Peak and Average Constraints: High SNR Capacity* - by A. Chaaban et al.

*Free-Space Optical Communication with Spatial Diversity Based on Orbital Angular Momentum of Light* - by G. Raof Mehrpoor et al.

*Outage Performance of Multi-Hop Hybrid FSO/RF Communication Systems* - by H. Kazemi et al.  
*10 Gbps All-Optical Relay-Assisted FSO System over a Turbulence Channel* - by N. A. Mohd Nor et al.  
*Effect of Partial Coherence on MISO FSO Systems* - by M. Gökçe et al.

#### **IWOW Session 4 - Optical Wireless Networks**

*Non-Orthogonal Multiple Access (NOMA) for Indoor Visible Light Communications* - by R. Kizilirmak et al.  
*Cooperative OFDM-based Multi-User Visible Light Communication Systems with Limited User Information* - by M. Kashef et al.  
*MU-MIMO Precoding for VLC with Imperfect CSI* - by H. Marshoud et al.  
*Adaptive Power Control Algorithms in Underwater Wireless Optical CDMA Cellular Networks* - by N. BaniHassan et al.



*Auditorium during Keynote speech and demo sessions*

#### **IWOW Poster Session 1**

*A Real-Time Platform for Collaborative Research on Visible Light Communication* - by C. Ribeiro et al.  
*Software Defined VLC System: Implementation and Performance Evaluation* - by W. Hussain et al.  
*Development and testing of an indoor VLC simulator* - by C. Capsoni and D. Tagliaferri  
*Low-Cost NIR Measurement Device* - by L. Mustafa and E. Černič  
*Photon Detection Characteristics and Error Performance of SPAD-Array Optical Receivers* - by E. Sarbazi et al.

#### **IWOW Poster Session 2**

*SEP analysis of FSO system employing SIM-MPSK with noisy phase reference* - by M. Petkovic and G. Djordjevic  
*Throughput Maximization in Hybrid FSO/RF Communication Systems* - by S. Enayati et al.  
*Non-Line-of-Sight Ultraviolet Communications over Atmospheric Turbulence Channels* - by M. Haghghi et al.  
*On the Performance of Satellite-to-Ground Optical Communication over Atmospheric Turbulence Channels with Pointing Errors* - by T. Özbilgin and S. Şahin  
*Polarization RIN of VCSEL Subject to Modulation Signal with Variable Polarization Angle of Optical Feedback* - by S. Ahmed et al.



## OPTICWISE: At the Forefront of International Standardization

### Here comes the LiFi

IEEE, the international standardization institution which developed today's widely used WiFi standard, has recently started working on visible light communication, also referred to as LiFi. The IEEE 802.15.7r "Short-Range Optical Wireless Communication" Task Group has been formed to develop an international LiFi standard and bi-monthly group meetings have been taking place since January 2015. On behalf of OPTICWISE, the Action Chair Prof. Uysal attends IEEE 802.15.7 meetings. He was also elected as a Technical Editor of the Task Group. It is expected that this standard will be finalized in the end of 2017.

The Task Group has so far prepared the Technical Considerations Document which will provide the basis of proposals to be collected in early 2016 and made selection on the LiFi channel models required for the comparative performance evaluations of different proposals. A remarkable success on OPTICWISE front was that the LiFi channels developed by OPTICWISE Action Chair Prof. Uysal were selected as the "Reference Channel Models" by the IEEE 802.15.7r Task Group during the meeting held in Bangkok, Thailand, in September 2015. Accordingly, all companies, universities and research institutions are required to use these channel models as reference for their performance assessments and comparative analysis in the standardization proposals they will submit over the coming months. Prof. Uysal emphasized that the channel models developed by them are the most realistic models available in the literature and pointed out the significance of recognition and adoption of these models by the industry.

### Towards 5G

OPTICWISE has achieved a great success by being admitted as an Associate Member of the 5G Infrastructure Public-Private Partnership (5G PPP). The 5G PPP is a joint initiative between the European ICT industry and the European Commission and has telecom giants Alcatel-Lucent, Ericsson, Nokia Solutions and Networks, Orange as its founding members. Total number of Associate Members of 5G PPP is up to thirty. OPTICWISE became the first non-legal entity to be admitted to this visionary initiative which will shape the next generation wireless networks.

Most European countries have already adopted 4G (also known as LTE-A) and are looking forward to deploying the

so-called 5G standard as early as 2020. The ultimate target of 5G PPP is to create this new standard that will provide ubiquitous ultra-fast connectivity and seamless service delivery. It is predicted that the new standard will deliver 1000 times the capacity of current mobile networks and reach peak data rates of over 10 Gbps. As an Associate Member of 5G PPP, OPTICWISE aims to take a leading role in promoting OWC to integrate it in the 5G standard as a powerful complementary technology to RF.

lectures to hands-on experimental studies for graduate students and ESRs in the OWC field.

OPTICWISE was very successful in positioning itself as an internationally recognized reference point in OWC field. It became the first non-legal entity to be admitted to 5G Infrastructure Public Private Partnership (PPP) which leads the European research activities on the global next generation mobile networks.

OPTICWISE also took a leading role in the launch of a new Task Group IEEE 802.15.7r which is currently developing an international standard on "Short Range Optical Wireless Communication". OPTICWISE participants actively contributed to the ongoing standardization activities which will be completed by the end of 2017. This standard will define PHY and MAC layers of next generation visible light communication (also known as LiFi) modems. It is projected that millions of people worldwide could use these standard compatible LiFi modems as alternative and/or complementary to existing WiFi technology.

While our Action comes to an end, a bright future lies ahead for optical wireless communication technologies. Building on the strong foundations of the Action, OPTICWISE community will continue to contribute to the advancement of this growing field.

OPTICWISE Action Chair  
Prof Dr Murat Uysal



## A Farewell with a Bright Future Ahead

It has been an exciting four years for European OWC community. Since its inception in 2011, OPTICWISE has played a key role in synergizing the interdisciplinary scientific expertise of European researchers in various scientific disciplines including the electromagnetic propagation theory, atmospheric physics, information/communication theory, networking, communication systems, photonic components, devices and systems. Through integrated research capability made possible by the OPTICWISE, Action participants have explored and developed novel methods, models, techniques, strategies and tools in infrared, visible and ultraviolet spectral bands. This resulted in more than 600 publications 114 of which are jointly authored. Such contributions have led to a much better understanding of OWC which was treated as a niche technology in the past. In addition to theoretical contributions, several Action participants have contributed to the design and building of proof-of-concept VLC and FSO systems demonstrating the promise of OWC systems for achieving low-cost, ultra-high-bandwidth, and reliable future generation heterogeneous communication networks.

Coordination efforts through OPTICWISE have helped avoid major duplications of research efforts and initiated many joint works providing opportunities for developing and sharing common software and hardware tools. One particular achievement was the building of a dedicated indoor atmospheric chamber for testing and characterization of FSO links. This chamber provided an opportunity for low cost experimental verification of FSO link performance and led to several joint publications. The mobility of OWC researchers in Europe significantly increased through Short Term Scientific Missions (STSMs). These research visits provided excellent opportunities for Early Stage Researchers (ESRs) to access to experimental setups which are not readily available at their home institutions. Training Schools organized by Action participants provided invaluable training opportunities ranging from theoretical

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### Website of the Action

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

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