# International Conference on Optical Wireless Communications

Beijing Friendship Hotel Beijing, China July 1-3, 2017



**Co-Sponsors** 

- Broadband Communication Key Laboratory, Tsinghua National Laboratory for Information Science and Technology, China
- Optical Wireless Communication and Networking Center, University of Science and Technology of China (USTC)
- National 973 Program of China
- National Natural Science Foundation of China

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## Welcome to OWC 2017

It is a great pleasure to invite you to attend the International Conference on Optical Wireless Communications (OWC 2017) to be held on July 1-3, 2017 in Beijing, and take this opportunity to discuss with international and national experts about state-of-the-art OWC technologies and applications, and its trend for future development. Since the last conference in Beijing on June 20, 2013 co-chaired by us, there have been numerous exciting activities and progresses on optical wireless communications globally, including various different-scale symposia and workshops, standardizations, industry-university associations, and emerging applications. In particular, large-scale LED industries and OWC applications in China motivate us to organize another such conference, to promote exchange and sharing of research results and progresses.

Sponsored by the Tsinghua National Laboratory for Information Science and Technology and the only National Key Basic Research Program (973) of China on Broad Spectrum OWC, the conference is scheduled in Beijing for 3 days. Registration takes place on July 1 (Saturday). The technical program on July 2-3 consists of more than 30 talks given by invited speakers from leading universities, institutions and companies, and panel sessions on OWC, from materials and devices to communications, positioning, systems, networks, and standardizations. It also covers applications in indoor, outdoor terrestrial, air, space, underwater, and data center, such as visible light communications, image sensor communications, positioning, vehicular communications, ultraviolet communications, and free space optical communications. OWC 2017 provides an ideal venue to keep up with frontier research and interact with top researchers. We would like to thank all the contributors and invited speakers who have spent much time contributing to this conference. We also appreciate attendees from academia and industry who participate this event.

In addition to the technical program, a rich social program is prepared to facilitate meeting and networking with colleagues/friends from all over the world. A banquet will be held in the evening on July 2.

It is a huge task to organize a conference and it is impossible to succeed without the dedicated efforts of many supporters and volunteers. We are grateful to the entire technical program sponsors led by Broadband Communication Key Laboratory, Tsinghua National Laboratory for Information Science and Technology, China; Optical Wireless Communication and Networking Center, University of Science and Technology of China (USTC); National 973 Program of China; National Natural Science Foundation of China. We also thank the staff and volunteers from Tsinghua University and USTC for organizing the event.

Hope you will enjoy the conference program.

Sincerely,

#### General Chairs

Zhengyuan Xu, University of Science and Technology of China

Zhaocheng Wang, Tsinghua University

## Welcome and Opening Remarks from Sponsors

#### -- Tsinghua National Laboratory for Information Science and Technology

On behalf of Tsinghua National Laboratory for Information Science and Technology (TNList), it is my great honor to welcome all the distinguished guests, from Canada, China, Greece, Israel, Japan, Netherlands, Saudi Arabia, United States of America, United Kingdom and etc., to attend 2017 International Conference on Optical Wireless Communications (OWC 2017), which will be held on July 1-3, 2017 in Beijing, China.

TNList is one in the first group of five national laboratories authorized on November 25, 2003 by the Ministry of Science and Technology, China. Its objective is to establish a world-class facility for planning and conducting scientific research to promote technological innovations that directly contribute to China's development and prosperity. The Laboratory is intended to become a magnet for world-class research in China, a place where leading scientists from all over the world can exchange visions and ideas, foster innovations, and create achievements with a significant social, scientific and economic impact.

TNList has been designed to leverage Tsinghua University's extensive resources in information science and technology and to develop a creative and open research environment. The Laboratory brings together three State Key Laboratories and three key laboratories from School of Information Science and Technology, Tsinghua University.

TNList, together with its six grade-one disciplines including computer science and technology, electronic science and technology, information and communication engineering, control science and engineering, software engineering, and cyber security from Tsinghua University, focuses on emerging new frontier and inter-disciplinary research areas. Its mission is to make scientific discoveries with a significant impact in the fundamental theory of information science, the acquisition and collection of information, the communication and networking of information, the processing and computation of information, the application of information technology, and scientific exploration based on advanced information technology.

Welcome to Beijing and enjoy OWC 2017.

#### Prof. Zhaocheng Wang

Director of Broadband Communication Key Laboratory Tsinghua National Laboratory for Information Science and Technology (TNList) Department of Electronic Engineering, Tsinghua University Beijing, 100084, P. R. China Email: zcwang@tsinghua.edu.cn



**Prof. Zhaocheng Wang** received his B.S., M.S., and Ph.D. degrees from Tsinghua University, in 1991, 1993, and 1996, respectively. From 1996 to 1997, he was a Post-Doctoral Fellow with Nanyang Technological University, Singapore. From 1997 to 1999, he was with the OKI Techno Centre Pte. Ltd., Singapore. From 1999 to 2009, he was with Sony Deutschland GmbH, Germany. He is currently a Professor of Dept. of Electronic Engineering with Tsinghua University and serves as the Director of Broadband Communication Key Laboratory, Tsinghua National Laboratory for Information Science and Technology. He has authored or co-authored over 130 journal papers and holds 34 granted U.S./EU patents. His research interests include visible light communications, millimeter wave communications, and

digital broadcasting. He served as an associate editor of IEEE Transactions on Wireless Communications from 2011 to 2015 and IEEE Communications Letters from 2013 to 2016, and has also served as the technical program committee co-chairs of various international conferences. He received ICC2013 Best Paper Award, OECC2015 Best Student Paper Award, 2016 IEEE Scott Helt Memorial Award (Best Paper Award of IEEE Transactions on Broadcasting), 2016 National Award for Science and Technology Progress (First Prize) and ICC2017 Best Paper Award. He is a fellow of the Institution of Engineering and Technology.

#### -- National 973 Project on Broad Spectrum Signal Transmission

#### Wireless Transmission Theory and Methods for Wide Optical Spectrum Signals

Zhengyuan Xu, University of Science and Technology of China

Wireless transmission of wide optical spectrum signals explores the rich optical spectra from infrared to visible light and ultraviolet bands, and utilizes semiconductor light sources with certain spectral width to achieve reliable and efficient signal transmission in space. Its unique features of unlicensed spectrum and anti-electromagnetic interference help to meet the needs of the future enhanced mobile broadband services, massive connections of things, and ultra-low latency communications. This talk will provide a comprehensive overview of the relevant research progresses of an on-going national 973 project on wireless transmission theory and methods for wide optical spectrum signals. It will cover not only signal propagation characteristics in an indoor multi-path or outdoor atmospheric scattering environment using single-element or arrayed transceiver units, as well as corresponding data modulation and detection techniques in the presence of system disturbance and imperfectness, but also exploration of rich multidimensional resources in space, time, frequency, code, wavelength, and amplitude. It will then address performance assessment and demonstrate some testing platforms. It will further present some examples of potential applications, such as indoor precise optical control of robots, internet access, image sensor communication, covert screen-camera communication, optical vehicle networking, and underwater communications.



**Professor Zhengyuan Xu** received his B.S. and M.S. degrees from Tsinghua University, Beijing, China, in 1989 and 1991, respectively, and Ph.D. degree from Stevens Institute of Technology, New Jersey, USA, in 1999. From 1991 to 1996, he was with Tsinghua Unisplendour Group Corporation, Tsinghua University, as system engineer and department manager. In 1999, he joined University of California, Riverside, first as Assistant Professor and then tenured Associate Professor and Professor. He was Founding Director of the multi-campus Center for Ubiquitous Communication by Light (UC-Light), University of California. In 2010, he was selected by the "Thousand Talents Program" of China, appointed as Professor at Tsinghua

University, and then joined University of Science and Technology of China (USTC) in 2013. He is Founding Director of the Optical Wireless Communication and Network Center, Founding Director of Wireless-Optical Communications Key Laboratory of Chinese Academy of Sciences, in USTC. He is also a chief scientist of the National Key Basic Research Program (973 Program) of China. His research focuses on wireless communications and networking, optical wireless communications, geolocation, intelligent transportation, and signal processing. He has published over 270 journal and conference papers, and co-authored a book titled *Visible Light Communications: Modulation and Signal Processing*, to be published by Wiley-IEEE Press. He has served as an Associate Editor and Guest Editor for different IEEE and OSA journals. He was a Founding Chair of IEEE Workshop on Optical Wireless Communications in 2010.

# Committees

## **General Chairs**

Zhengyuan Xu, Professor, University of Science and Technology of China, xuzy@ustc.edu.cn Zhaocheng Wang, Professor, Tsinghua University, zcwang@tsinghua.edu.cn

## Local Organizing Committee

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### **Co-Sponsors**

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- National Natural Science Foundation of China

# **General Information**

Conference Venue: Beijing Friendship Hotel, Beijing

Address:1 Zhongguancun South St. Beijing 100873, P.R. ChinaTelephone:0086-10-68498888



## Accessibility

The Friendship Hotel of Beijing is one of the largest garden-style hotels in Asia. Located in the heart of ZhongGuanCun Hi-Tech Zone, the Friendship Hotel neighbors many world famous tourist sites and universities such as Tsinghua University, Peking University, the Summer Palace.

## Transportation

Starting	km	Type of Transportation	
	34	Take the shuttle bus (Capital Airport to Gongzhufen), and get off at the stop of Friendship Hotel.	
Capital Airport		Take Airport Express to Sanyuanqiao station then Subway line 10 to Haidianhuangzhuang station, and transfer to Subway line 4 to Renmin University station. Please use Exit D	
Beijing Railway Station	18	Take subway line 2 at Beijing station, transfer to line 4 at Xuanwumen station, and get off at Renmin University station. Please use Exit D.	
Beijing South Railway Station	25	Take subway line 4, and get off at Renmin University station. Please use Exit D.	
Beijing North Railway Station	5	Take subway line 4, get off at Renmin University station. Please use Exit D.	
Tiananmen Square	13	Take subway line 1 at Tiananmen East or Tiananmen West station, transfer to line 4, and get off at Renmin University station. Please use Exit D.	



## Lunch

Tickets for the lunch during the conference have been placed in the document bag. Please show your tickets for meal when necessary.

## Contact

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#### Webpage:

http://owc.ustc.edu.cn/news/academic\_conference/

# Agenda

July 1, Sat	urday				
14:00-22:00	Registration				
July 2, Sur	nday				
Time	Торіс	Speaker	Affiliation		
08:00-17:30	Reg	istration			
	Welcome and Opening Remarks from Spon	sors			
08:30-09:10	Tsinghua National Laboratory for Information Science and Technology	Zhaocheng Wang	Tsinghua University, China		
	National 973 Project: Wireless Transmission Theory and Methods for Wide Optical Spectrum Signals	Zhengyuan Xu	University of Science & Technology of China		
	Session 1: VLC Positioning				
	Chair: Thomas Little, Boston University,	Chair: Thomas Little, Boston University, USA			
	Indoor Positioning and Tracking Using Visible Light Communications	Maite Brandt-Pearce	University of Virginia, USA		
09:10-10:30	Methods for Overcoming the Multipath Effects, Light Intensity Fluctuation and Masking of Light in a VLC Positioning System	Aiying Yang	Beijing Institute of Technology, China		
	Indoor Visible Light Positioning Technology: Overview, State of the Art, and Recent Progress	Julian Cheng	University of British Columbia, Canada		
	Space-Time-Multiplexed Multi-Image Visible Light Positioning System Exploiting Pseudo-Miller-Coding for Smart Phones	Ming Jiang	Sun Yat-sen University, China		
10:30-11:00	0:30-11:00 Coffee/Tea Break				
	Session 2: Systems and Networks Chair: George K. Karagiannidis, Aristotle University of Thessaloniki, Greece				
11:00-12:00	Lighting Beyond Illumination	Hans Nikol	Philips Lighting, Netherlands		
	Promising Long-haul Heterogeneous Interconnection Architecture	Zhitong Huang	Beijing Univ. of Posts & Telecommunications, China		
	VLC for Dense Networking in Indoor Spaces	Thomas Little	Boston University, USA		

12:00-14:00	L	unch	
	Session 3: Transmission Systems I		
14:00-15:20	Chair: Mohamed-Slim Alouini, KAUST, S	Saudi Arabia	
	OFDM for Visible Light Communications – Is It the Right Option?	Zabih Ghassemlooy	Northumbria University, UK
	High Speed Pulse Amplitude Modulation in Visible Light Communication	Nan Chi	Fudan University, China
	High-speed Image Processing of VLC Signals for Automotive Applications	Takaya Yamazato	Nagoya University, Japan
	Improved Multi-carrier Modulation Schemes for Visible Light Communications	Zhaocheng Wang	Tsinghua University, China
15:20-15:50	Group Photo,	Coffee/Tea Break	
	Session 4: Transmission Systems II		
	Chair: Shinichiro Haruyama, Keio Univer	rsity, Japan	
15:50-16:50	Simultaneous Lightwave Information and Power Transfer (SLIPT) for Indoor IoT Applications	George K. Karagiannidis	Aristotle University of Thessaloniki, Greece
	Biased Beamforming for Multi-LED Multi- Carrier Visible Light Communication	Jiaheng Wang	Southeast University, China
	On the Potential of Coordinated Transmission in LiFi Systems	Lutz Lampe	University of British Columbia, Canada
Panel DiscussionChair: Zabih Ghassemlooy, Northumbria University, UKPanelists:Mohamed-Slim Alouini, KAUST, Saudi ArabiaMaite Brandt-Pearce, University of Virginia, USA16:50-17:50Nan Chi, Fudan University, ChinaHarald Haas, University of Edinburgh, UKMitsuji Matsumoto, Waseda University, JapanHans Nikol, Philips Lighting, NetherlandsZhaocheng Wang, Tsinghua University, ChinaDong Wei, Huawei, USA			
July 3, Mo	nday		
Time	Topic	Speaker	Affiliation
08:00-17:30	Reg	istration	
08:30-10:10	Session 5: Standards and Applications Chair: Maite Brandt-Pearce, University o	f Virginia, USA	

	A Light-Connected World	Harald Haas	University of Edinburgh, UK
	Optical Wireless Communication (OWC): IoT & Smart City Enabler	Carsten Kausch	Audi China R&D
	Standardization of Visible Light Communication in ITU	Dong Wei	Huawei, USA
	Standardization of Optical Wireless Communication in IEEE 802	Qiang Li	HiSilicon, Huawei Technologies, China
	Visible Light Beacon System for Multimedia Applications	Shinichiro Haruyama	Keio University, Japan
10:10-10:40	Coffee	/Tea Break	
	Session 6: Devices and Systems		
	Chair: Nan Chi, Fudan University, China		
10:40-12:00	Consideration on Transmission Characteristics of Optical Wireless Communication Systems	Mitsuji Matsumoto	Waseda University, Japan
	Diffractive Optical Elements for Visible Light Communication	Huarong Gu	Tsinghua University, China
	GaN-based LEDs for Visible Light Communication	Lixia Zhao	Institute of Semiconductors, CAS, China
	ZnO-Based Ultraviolet Photodetectors	Kewei Liu	Changchun Institute of Optics, Fine Mechanics and Physics, CAS, China
12:00-14:00	L	lunch	
	Session 7: Atmospheric and Underwater (	OWC	
	Chair: Shlomi Arnon, Ben-Gurion Univer	sity of the Negev, Israe	1
14:00-15:40	High-speed Underwater Wireless Optical Communication: Potential, Challenges, and Possible Solutions	Mohamed-Slim Alouini	KAUST, Saudi Arabia
	Underwater Wireless Optical Communication: Where, When, and How?	Jing Xu	Zhejiang University, China
	Recent Progress on the Optical Wireless Scattering Communication	Chen Gong	University of Science and Technology of China
	A LDPC Code for Non-line-of-sight Ultraviolet Communication	Yong Zuo	Beijing University of Posts and Telecommunications, China

	Techniques for Atmospheric Optical Communication Channel Monitoring and Link Availability Forecasting	Haiping Mei	Anhui Institute of Optics & Fine Mechanics, CAS, China
15:40-16:10	Coffee	/Tea Break	
	Session 8: OWC for Future Applications Chair: Lutz Lampe, University of British	Columbia, Canada	
16:10-17:30	Augmented Data Centers Network by Optical Wireless Links	Shlomi Arnon	Ben-Gurion University of the Negev, Israel
	Real Time Visible Light Communication System based on Phosphor Coated Blue LED	Xiongbin Chen	Institute of Semiconductors, CAS, China
	Connected Lights: Paving The Way for User-Centric Design	Rong Zhang	University of Southampton, UK
	Optical Wireless Communications Technology Based Internet of Things	Xuan Tang	Fujian Institute of Research on the Structure of Matter, CAS, China
17:30	Con	nclusion	

## **Technical Sessions**

Session 1: VLC Positioning

Su1.1

#### Indoor Positioning and Tracking using Visible Light Communications

Maïté Brandt-Pearce, University of Virginia, USA

The problem of positioning and tracking of user equipment indoors has garnered interest as communication systems and mobile device capabilities advance. Visible light communication (VLC) is an alternative to RF or Wi-Fi methods that uses light emitting diodes, is not susceptible to electromagnetic interference, and can operate in RF-prohibited environments. In this talk, we present a series of algorithms that can locate and track mobile devices using non-imaging receivers and a fingerprint mapping technique. Our approaches rely on the received light characteristics and can either be performed by the mobile unit or at the network side. The performance of our methods is shown to be more reliable for indoor positioning and tracking than trilateration-based methods. The accuracy of our algorithms is on the order of the grid resolution of the fingerprint map for high signal-to-noise ratio environments.



Dr. Maïté Brandt-Pearce is professor of Electrical and Computer Engineering and Executive Associate Dean for Academic Affairs of the School of Engineering and Applied Sciences at the University of Virginia. She joined UVa after receiving her Ph.D. in Electrical Engineering from Rice University in 1993. Her research interests include nonlinear effects in fiber-optics, free-space optical communications, crosslayer design of optical networks subject to physical layer degradations, body area networks, and radar signal processing. Dr. Brandt-Pearce is the recipient of an NSF CAREER Award and an NSF RIA. She is a co-recipient of Best Paper Awards at ICC 2006 and GLOBECOM 2012. She had served on the editorial board of IEEE Transaction of Communications, IEEE Communications Letters, IEEE/OSA

Journal of Optical Communications and Networks and Springer Photonic Network Communications. She was Jubilee Professor at Chalmers University, Sweden, in 2014. After serving as General Chair of the Asilomar Conference on Signals, Systems & Computers in 2009, she was selected as Technical Vice-Chair of GLOBECOM 2016. She is a member of Tau Beta Pi, Eta Kappa Nu, and a Senior Member of the IEEE. In addition to co-editing a book entitled Cross-Layer Design in Optical Networks, Springer Optical Networks Series, 2013, Prof. Brandt-Pearce has over one hundred and eighty technical publications.

## Methods for Overcoming Multipath Effects, Light Intensity Fluctuation and Masking of Light in a VLC Positioning System

Aiying Yang, Beijing Institute of Technology, China

With the rapid development of smart technology, the need for location based services (LBS) increases every day. Since classical positioning technology such as GPS cannot satisfy the needs of indoor positioning, new indoor positioning technologies have emerged, such as Bluetooth, Wi-Fi and Visible light communication (VLC). VLC positioning technology is a promising candidate because it has higher accuracy, lower cost and is easier to accomplish in comparison to the other indoor positioning technologies. However, the practicality of VLC positioning is limited since it is easily affected by multipath effects, light intensity fluctuation and the mask of light from LEDs. In this presentation, we reported our work on overcoming these limitations. We first presented a differential detection based positioning algorithm to reduce positioning instability caused by light intensity fluctuation. Then, we introduced a received signal strength based iterative visible light positioning algorithm and an ANN based VLC positioning algorithm to suppress the effect diffuse reflection. Finally, we demonstrated the fusion positioning systems based on a particle filter and an extended Kalman filter to solve the problem of light masking. The experimental results showed that the accuracy of the hybrid localization system was in centimeters, which outperformed the VLC based positioning or inertial navigation alone.



**Prof. Aiying Yang** received the B. S. in Physics from Jilin University, China, in 1997. She received the Ph. D degree in Information and Communication system from Peking University, China, in 2003. She is currently a professor with the School of Opto-electronics at Beijing Institute of Technology, China. She is a member of the IEEE and the OSA. Her current research interests are in optical fiber communications, visible light communications and indoor positioning. She has more than 21 publications and 8 authorized patents on the research of visible light communications and indoor positioning.

## Indoor Visible Light Positioning Technology: Overview, State of the Art, and Recent Progress

#### Julian Cheng, University of British Columbia, Canada

Due to the increasing demands for indoor location-based services, wireless indoor positioning system has attracted much research and development attention in recent years, and the market size for indoor positioning has been assessed to be tens of billions of dollars. Compared with other indoor positioning technologies such as radio frequency, infrared and ultra-sound, visible light positioning technology has the advantages of simpler infrastructure, more efficient energy use, and higher positioning accuracy. In this talk, we will first provide an overview of indoor positioning using visible light and its state of the art. While positioning with visible light communication (VLC) infrastructure can achieve centimeter-level accuracy, most existing VLC-positioning system prototypes have some practical limitations. To overcome these limitations, we propose a new VLC positioning technique called angle difference of arrival (ADOA), which allows for arbitrary tilting and pitching of the receivers. We demonstrate both numerically and experimentally that the proposed VLC positioning system based on ADOA can achieve accuracy of less than 1 centimeter. The proposed VLC positioning technology, which has both low cost and low complexity, can be used in a wide variety of indoor positioning applications.



**Prof. Julian Cheng** received his PhD degree in electrical engineering from the University of Alberta, Edmonton, AB, Canada. He is currently a Full Professor in the School of Engineering at The University of British Columbia, Okanagan campus in Kelowna, BC, Canada. His current research interests include wireless communication theory, wireless networks, optical wireless communications, and quantum communications. Dr. Cheng served as a member of technical program committee for many IEEE conferences and workshops. He co-chaired the 12th Canadian Workshop on Information Theory (CWIT 2011) in Kelowna, Canada. In 2012, he chaired the 2012 Wireless Communications in Banff, Canada. Dr. Cheng also chaired the sixth IEEE Optical Wireless Communications Symposium at the 2015 IEEE Global Communications Conference. Currently, he

serves as an Editor for *IEEE Transactions on Communications, IEEE Transactions on Wireless Communications, IEEE Communications Letters, IEEE Access,* as well as a past Guest Editor for a special issue of *IEEE Journal on Selected Areas in Communications* on optical wireless communications.

# Su1.4

## Space-Time-Multiplexed Multi-Image Visible Light Positioning System Exploiting Pseudo-Miller-Coding for Smart Phones

Ming Jiang, SunYat-sen University, China

Visible light communication based schemes utilising LED identifiers are among the most popular candidate solutions for indoor localisation applications. In this work, we design a comprehensive imaging visible light positioning system, which exploits off-the-shelf LED lamps and commercial user equipment employing a rolling shutter aided CMOS image sensor. More specifically, we first introduce an asynchronous oversampled multi-image detection scheme inspired by the rationale of Miller coding, which efficiently solves the synchronisation problem in transmissions of LED identifiers. Then, a discrete Fourier transform aided LED flicker frequency detection algorithm is detailed for robust single-image detection. Furthermore, we extend the proposed method to a space-time-multiplexing framework, which improves the overall transmission rate and solves the problem of detecting the user's moving direction. The notable advantages of the new solution are demonstrated through both practical measurements and computer simulations.



**Prof. Ming Jiang** received B.Eng. and M.Eng. degrees from South China University of Technology (SCUT), China, and Ph.D. degree from University of Southampton, UK, respectively, all in Electronic Engineering. Dr. Jiang has substantial international and industrial experience with Fortune 500 telecom companies. From 2006 to 2013, he had held key R&D and/or management positions at Samsung Electronics Research Institute (SERI), UK, Nortel's R&D Centre, China, and telecom equipment maker New Postcom, China, where he actively participated in numerous collaborative projects including European FP6 WINNER-II, FP7 DAVINCI, WiMAX/IEEE802.16m and LTE/LTE-A standardization, etc. across the EU, North America and Asia, on

researching and designing novel algorithms, telecommunication standards as well as radio access and core network products. In June 2013, he joined Sun Yat-sen University, China, as a Full Professor and Ph.D. Supervisor, where he focuses on both scientific research and technology transfer with industrial partners. Dr. Jiang's research interest falls into next-generation wireless mobile communications, including VLC, MIMO, OFDM, D2D, HetNets, etc. He has co-authored or contributed to 5 Wiley books, 40+ papers in prestigious international journals and conferences, 40+ patents as well as 400+ LTE/LTE-A/WiMAX standardization contributions. Dr. Jiang is an IEEE Senior Member and a recipient of several Chinese Council Awards in 2011, including Innovative Leading Talents, Outstanding Experts, and Top Overseas Scholars.

#### Session 2: Systems and Networks

Su2.1

#### **Lighting Beyond Illumination**

Hans Nikol, VP-Open Innovation, Philips Lighting, Netherlands

The talk consists of four parts: 1. Introduction of Philips Lighting; 2. Innovation in Philips Lighting & IoT strategy; 3. LiFi cases introduction (VLC in Carrefour, Venture of LiFi); 4. Outlook of future possible application with LiFi.



**Dr. Hans Nikol** studied in chemistry in Germany, followed by a postdoc at Caltech, USA. In 1995, he joined Philips Research to work on LED materials. In 2004, he transferred to Philips Lighting to continue with LED system development. In 2006, he joined newly founded LED business group as CTO to develop LED lamps and systems for the emerging LED Lighting market. In 2011, he continued to work on LED platforms with a build-up of a new supply base in Asia. Since 2013, he has been working in Open Innovation to focus on the emerging digital Lighting market with Lighting being one of the most interesting verticals in IoT.

## Promising Long-haul Heterogeneous Interconnection Architecture with Indoor VLC Networks

Zhitong Huang, Beijing University of Posts and Telecommunications, China

Due to the large-scale deployment of the white light-emitting-diode (LED) as the next-generation green lighting, the visible light communication (VLC), which utilizes the incoherent lightwave of LED to transfer information in free space, has been presented as a popular solution for indoor short-distance broadband access. With the progresses of advanced modulation, equalization and multiplexing schemes, along with the manure of the corresponding integrated-circuit chips, it is now available to achieve Gb/s VLC transmission. Currently more research interests have been moved to the network-layer mechanisms such as cell construction, multi-user access, and Li-Fi/Wi-Fi co-existence. The corresponding outdoor long-haul network infrastructure is always a hotspot for VLC research since the PLC, LTE and even the GPON techniques are not adequate to provide enough bandwidth. In this speech, we present two promising solutions. The first is the fiber-VLC heterogeneous interconnection which uses hybrid space-division-multiplexing and wavelength-division-multiplexing, which will be more suitable to be deployed for terrestrial applications. The other is the FSO/VLC heterogeneous interconnection, which will be promising for the future space-air-ground-ocean integrated communication network. The key elements for the above two heterogeneous interconnection architectures are discussed, along with the implementation details.



**Prof. Zhitong Huang** received his Ph.D. in 2008 in School of Electronic Engineering at Beijing University of Posts and Telecommunications (BUPT), Beijing, P.R. China. He is now an associate professor of BUPT, and his research interests are in the areas of visible light communication, optical wireless communication networks. He has participated in a number of national projects, published more than 50 SCI/EI papers, holds more than 15 invention patents, and obtained 2 academic awards including Ministry of Education Science and Technology Second Class Award, China Institute of Communications Science and Technology First Class Award.

## VLC for Dense Networking in Indoor Spaces

Thomas DC Little, Boston University, USA

Visible Light Communication (VLC) is an intriguing technology that has received substantial recent attention in the research community for its ability to realize new spectrum, increase security, and support novel light-based applications. But it does not exist in a vacuum; sensing and communication techniques exist in the RF world that compete for similar performance objectives. Of the many ways to use VLC, we focus on VLC as an indoor wireless access medium, and increasingly, how VLC can be adopted as part of the "5G" vision.

In this talk we describe the properties of VLC that make it suitable as a 5G technology, including the ability to realize small cells, dense networking, and high user locality. We also describe some of the remaining challenges to adoption. Finally, we demonstrate how RF and VLC can coexist, realizing the strengths of both media, partnering to keep up with the insatiable demand for more data connectivity.



**Prof. Thomas DC Little** is a professor in the Department of Electrical and Computer Engineering at Boston University. He is Associate Director of the National Science Foundation Engineering Research Center for Lighting Enabled Systems and Applications (LESA), a collaboration of Rensselaer Polytechnic Institute, the University of New Mexico, and Boston University. His recent efforts address research in pervasive computing using wireless technologies. This includes video streaming, optical communications with the visible spectrum, and applications related to ecological sensing, vehicular networks, and wireless healthcare. Dr. Little received his BS degree in biomedical engineering from

RPI in 1983, and his MS degree in electrical engineering and PhD degree in computer engineering from Syracuse University in 1989 and 1991. He is a Senior Member of the IEEE, a member of the IEEE Computer and Communications Societies and a member of the Association for Computing Machinery.

#### Session 3: Transmission Systems I

#### Su3.1

#### **OFDM for Visible Light Communications – Is It the Right Option?**

Zabih Ghassemlooy, Northumbria University, UK

In indoor applications, VLC can provide data communications, localization and sensing by simply using the light emitting diodes (LED) based lighting fixture. However, the VLC technology faces a number of challenges. The traditional complex and bipolar OFDM, proposed for RF systems, is modified for use in VLC systems in order to combat multipath induced distortion and boost the data rate without any bandwidth or power expansion. However, in OFDM-VLC systems there are a number of issues. In VLC systems with nonlinear LED power-current characteristics, higher PAPR results in severe distortion and clipping, thus leading to a decreased signal-to-quantization noise ratio in both ADCs/DACs. Compared to the RF-based wireless outdoor channels, an indoor environment is relatively static (mobility is very low) with no deep fading and therefore multipath induced interference is not a major issue. Therefore, the justification for using OFDM-VLC in such environments would be mainly to increase the data rate but at the cost of higher PAPR. However, there is still an open question if there are any advantages in adopting OFDM in VLC systems for the indoor environment? This talk will try to address this fundamental question.



**Prof. Zabih Ghassemlooy** received the B.Sc. degree (Hons.) in electrical and electronics engineering from Manchester Metropolitan University, Manchester, U.K., in 1981, and the M.Sc. and Ph.D. degrees from the Institute of Science and Technology, Manchester, University of Manchester, U.K., in 1984 and 1987, respectively. In 1988, he joined Sheffield Hallam University as a Lecturer, becoming a Reader in 1995 and became a Professor in optical communications in 1997. 2004 joined the University of Northumbria (UNN), Newcastle, as an Associate Dean (AD) for research with the School of Computing, Engineering, and Information Sciences, and from 2012 to 2014,

he was AD of Research and Innovation, Faculty of Engineering, UNN, UK, where he currently is Head of the Northumbria Communications Research Laboratories. In 2001 he was awarded the Tan Chin Tuan Fellowship in Engineering from the Nanyang Technological University in Singapore. 2016 he become a Research Fellow at the Chines Academy of Science, and since 2015 has been a Distinguished Professor with the Chinese Academy of Sciences, Quanzhou, China. He published over 675 papers (251 journals and 6 books), over 88 keynote and invited talks, and supervised 55 Ph.D. students. He was the Vice-Chair of EU Cost Action IC1101 (2011-16). He is the Chief Editor of the British Journal of Applied Science and Technology and the International Journal of Optics and Applications. He is the fellow of the IET, a senior member of IEEE, and a member of OSA. He is a co-author of a CRC book on "Optical Wireless Communications – Systems and Channel Modelling with Matlab (2012); and co-editor of three books.

#### Su3.2

## High Speed Pulse Amplitude Modulation in Visible Light Communication

Nan Chi, Fudan University, Shanghai, China

Visible Light Communications (VLC) is an emerging field of optical communications that focuses on the part of the electromagnetic spectrum that humans can see. One of potential application scenarios of high-speed VLC is for mobile back-hauling of small cells in next generation mobile networks. Within this scenario VLC can provide connectivity both in building and outdoor, and with a very competitive CAPEX/OPEX compared with millimeter wave communication, or even more competitive due to the lower device cost. PAM has become a promising modulation scheme in VLC systems because of the benefits in low complexity, flexible implementation and simple structure.

In this talk we summarize our research work about PAM-VLC system including PS-Manchester coding, weighted pre-equalization, Nyquist filter, phase estimation and S-MCMMA post-equalization in time-domain, a normal frequency-domain equalization and multi-band access. These enabling technologies can support PAM-VLC up to 4Gb/s free space transmission.



**Prof. Nan Chi** received the BS degree and PhD degree in electrical engineering from Beijing University of Posts and Telecommunications, Beijing, China in 1996 and 2001, respectively. From July 2001 to December 2004, she worked as assistant professor at the Research Center COM, Technical University of Denmark. From January 2005 to April 2006, she was a research associate at the University of Bristol, United Kingdom. Then in June 2006, she joined Wuhan National Laboratory for Optoelectronics, Huazhong University of Science and Technology, where she worked as a full professor. She joined the Fudan University since June 2008, in School of Information Science and Engineering.

She is the author or co-author of more than 300 papers. She has been awarded as the New Century Excellent Talents Awards from the Education Ministry of China, Shanghai Shu Guang scholarship, Pujiang talent of Shanghai City, Ten Outstanding IT Young Persons awards of Shanghai City. Her research interests are in the area of coherent optical transmission, visible light communication and optical packet/burst switching.

#### Su3.3

#### High-speed Image Processing of VLC Signals for Automotive Applications

Takaya Yamazato, Nagoya University, Japan

Triggered by Google's driverless car, a vehicle automation technology is currently a hot topic and is being worldwide developed in a rush for the first launch in the 2020s. An autonomous and connected vehicle relies on many internal sensors such as GPS, ultrasonic sensors, radar, and various vehicle sensors. Among those, vision sensors provide the "eyes" for autonomous driving. Two of the most important vision sensors are light detection and ranging (LIDAR) and image sensors (cameras). LIDAR emits an infrared laser beam and calculates the distance of objects within an accuracy of a few centimeters. It outputs modest resolution images within the infrared spectrum at approximately a 10 Hz rate. In contrast images sensors are used to identify objects, such as other vehicles, pedestrians, debris, signs, traffic lights, and lane markings. Because of the high resolution and color recognition, image sensors understand the scene that cannot be learned from lower-resolution LIDAR. Both image sensors and LIDAR can be used for localization. A noteworthy feature of an image sensor is that it can be used as a reception device for visible light communication (VLC) signal. For example, LEDs in a traffic light broadcast data via an infrastructure-to-vehicle visible light communication (I2V-VLC) signal and an on-board image sensor receiver can retrieve these data. LED brake lights in a lead vehicle transmit data to the following vehicle via a vehicle-to- vehicle visible light communication (V2V-VLC) signal, and an on-board image sensor receiver can retrieve the data.

In this talk, I will provide some of our research results on VLC for automotive application. Our uniqueness is mainly in a high-speed image processing that captures images 1,000 frames per seconds or more. I will talk in detail how we capture and decode VLC signals. Also, a precise localization using phase-only-correlation will be presented.



**Dr. Takaya Yamazato** is a professor at the Institute of Liberal Arts and Sciences, Nagoya University, Japan. In 1998, he gave a half-day tutorial entitled "Introduction to CDMA ALOHA" at Globecom held in Sydney, Australia. In 2006, he received the IEEE Communication Society's Best Tutorial Paper Award. He served as the co-chair of the Wireless Communication Symposia of ICC 2009 and is the co-chair of Selected Areas in Communication Symposia of ICC 2011. From 2008 to 2010, he served as the chair of the Satellite and Space Communication Technical Committee. In 2011, he gave a half-day tutorial entitled "Visible Light

Communication" at ICC 2011 held in Kyoto, Japan. From 2016, he is the Director of Asia/Pacific Board. His research interests include visible light communication (VLC), intelligent transport system (ITS), stochastic resonance (SR), and open educational resources (OER).

#### Su3.4

#### Improved Multi-carrier Modulation Schemes for Visible Light Communications

#### Zhaocheng Wang, Tsinghua University, China

Orthogonal frequency division multiplexing (OFDM) is attracting increasing attention in visible light communications due to its inherent benefits such as high spectral efficiency and resistance to frequency-selective channels. Since DC-biased optical OFDM (DCO-OFDM) suffers from energy efficiency loss due to the insertion of DC bias, and asymmetrically clipped optical OFDM (ACO-OFDM), pulse-amplitude modulated discrete multi-tone (PAM-DMT), and hybrid ACO-OFDM (HACO-OFDM) are spectrally inefficient and do not work well under dimming control, several energy- and spectrum- efficient optical OFDM schemes are proposed and summarized in this paper, including layered ACO-OFDM (LACO-OFDM) and asymmetrical hybrid optical OFDM (AHO-OFDM). In addition, by taking advantage of the inherent signal symmetry properties of ACO-OFDM and PAM-DMT in the time domain, pairwise clipping is utilized to further reduce the effect of noise and estimation error, resulting in improved performance.



**Prof. Zhaocheng Wang** received his B.S., M.S., and Ph.D. degrees from Tsinghua University, in 1991, 1993, and 1996, respectively. From 1996 to 1997, he was a Post-Doctoral Fellow with Nanyang Technological University, Singapore. From 1997 to 1999, he was with the OKI Techno Centre Pte. Ltd., Singapore. From 1999 to 2009, he was with Sony Deutschland GmbH, Germany. He is currently a Professor of Dept. of Electronic Engineering with Tsinghua University and serves as the Director of Broadband Communication Key Laboratory, Tsinghua National Laboratory for Information Science and Technology. He has authored or co-authored over 130 journal papers and holds 34 granted U.S./EU patents. His research interests include visible

light communications, millimeter wave communications, and digital broadcasting. He served as an associate editor of IEEE Transactions on Wireless Communications from 2011 to 2015 and IEEE Communications Letters from 2013 to 2016, and has also served as the technical program committee co-chairs of various international conferences. He received ICC2013 Best Paper Award, OECC2015 Best Student Paper Award, 2016 IEEE Scott Helt Memorial Award (Best Paper Award of IEEE Transactions on Broadcasting), 2016 National Award for Science and Technology Progress (First Prize) and ICC2017 Best Paper Award. He is a fellow of the Institution of Engineering and Technology.

## Session 4: Transmission Systems II

#### Su4.1

## Simultaneous Lightwave Information and Power Transfer (SLIPT) for Indoor IoT Applications

#### George K. Karagiannidis, Aristotle University of Thessaloniki, Greece

The era of Internet-of-Things (IoT) opens up the opportunity for a number of promising applications in smart buildings, health monitoring, and predictive maintenance. It is remarkable that most of the data consumption/generation, which are related to IoT applications, occurs in indoor environments. Motivated by this, optical wireless communication (OWC), such as visible light communications (VLC) or infrared (IR), have been recognized as promising alternative/complimentary technologies to RF, in order to give access to IoT devices in indoor applications. However, due to the strong dependence of the IoT on wireless access, their applications are constrained by the finite battery capacity of the involved devices.

In this talk, for first time will be presented a framework for simultaneous optical wireless information and power transfer, which we call Simultaneous Lightwave Information and Power Transfer (SLIPT), and can be used for indoor IoT applications through VLC or IR systems.



Prof. George K. Karagiannidis is currently Professor in the Electrical & Computer Engineering Dept. and Director of Digital Telecommunications Systems and Networks Laboratory. He is also Honorary Professor at South West Jiaotong University, Chengdu, China. His research interests are in the broad area of Digital Communications Systems and Signal processing, with emphasis on Wireless Communications, Optical Wireless Communications, Wireless Power Transfer and Applications, Molecular and Nanoscale Communications, Stochastic Processes in Biology

and Wireless Security. He is author or co-author of more than 450 technical papers published in scientific journals and presented at international conferences. He is also co-author of the book "Advanced Optical Wireless Communications Systems", Cambridge Publications, 2012. He was Editor in IEEE Transactions on Communications, Senior Editor of IEEE Communications Letters, and several times Guest Editor in IEEE Selected Areas in Communications. From 2012 to 2015 he was the Editor-in Chief of IEEE Communications Letters. Dr. Karagiannidis is one of the highly-cited researchers across all areas of Electrical Engineering, recognized as 2015 and 2016 Thomson Reuters highly-cited researcher.

#### Su4.2

## Biased Beamforming for Multi-LED Multi-Carrier Visible Light Communication

#### Jiaheng Wang, Southeast University, Nanjing, China

Visible light communication (VLC) can simultaneously offer high-speed transmission and controllable illumination, which is referred to as communication-lighting integration, and has emerged as an eco-friendly green communication technology with high energy efficiency, especially in indoor environment. The current illumination systems are commonly equipped with multiple light sources. Spatially distributed illumination sources make the system robust to blockage and shadowing effects, and thus can provide ubiquitous coverage in indoor environments for both communication and illumination. However, due to the nonlinear distortion, each LED may interfere and pollute the other LEDs' signals, which thus calls for a delicate design of coordinated transmission of multiple LEDs.

In this talk, we will introduce the new concept of biased beam forming to explore the full potential of multi-LED multicarrier VLC systems. Biased beam forming includes two components to be jointly designed: a direct current (DC) bias on each LED and a beam forming vector on each subcarrier. First, we will discuss the beam former design and analytically characterize the structure of the optimal beam former. Then, we further consider the bias optimization jointly with the beam former. The optimal bias is analytically characterized for flat channels along with several critical insights, and the efficient bias optimization algorithm is proposed for dispersive channels. The superiority and benefits of the proposed biased beamforming design are verified by numerical results. Due to its simplicity and flexibility, the biased beamforming is a promising technology for multi-LED VLC networks.



**Prof. Jiaheng Wang** received the Ph.D. degree in electronic and computer engineering from the Hong Kong University of Science and Technology, Kowloon, in 2010, and the B.E. and M.S. degrees from the Southeast University, Nanjing, China, in 2001 and 2006, respectively. He is currently a Full Professor at the National Mobile Communications Research Laboratory (NCRL), Southeast University, Nanjing, China. From 2010 to2011, he was with the Signal Processing Laboratory, KTH Royal Institute of Technology, Stockholm, Sweden. He also held visiting positions at the Friedrich Alexander University Erlangen-Nürnberg, Nürnberg, Germany, and the University of Macau, Macau. His research interests are mainly on optimization

in communication systems and wireless networks.

## On the Potential of Coordinated Transmission in LiFi Systems

Lutz Lampe, University of British Columbia, Canada.

Visible light communication (VLC) is an innovative technology that turns light emitting diode (LED)-based luminaires into wireless access points for ubiquitous broadband connectivity. The quality of service at cell-edge users severely deteriorates. Furthermore, the signal leakage across different atto-cells may give rise to security issues, especially in public spaces wherein passive eavesdroppers can go undetected.

In this talk, we highlight the potential of using coordinated transmission schemes among LiFi attocells for interference management and information security. Depending on the capacity of the backhaul network that interconnects the atto-cells, different levels of coordination can be implemented. With high-speed optical fiber-based backhaul networks, full coordination (or joint transmission) can be achieved wherein the channel state information (CSI) and data symbols of all the users are exchanged among all the cooperative atto-cells. With such full coordination, the attocells become equivalent to a single multi-luminaire transmitter that serve all the users. On the other hand, when the backhaul connectivity is achieved with lower bandwidth, partial coordination can be achieved where only CSI is exchanged among the cooperative atto-cells, and each user is served only by one transmitter. This coordinated transmission scheme strikes a balance (in performance and backhaul overhead traffic) between joint transmission and non-coordinated transmission. We also propose the use of the excess spatial degrees of freedom (resulting from having multiple luminaries in each atto-cell) in order to achieve secure communications at the physical layer. Our idea is to transmit directive beams that relay information towards the intended receivers while minimizing the signal leakage to users in neighbouring atto-cells.



**Dr. Lutz Lampe** is a full professor in the Department of Electrical and Computer Engineering at the University of British Columbia, Canada. His research interests are broadly in theory and application of wireless, optical wireless, and power line communications, including visible light communications. He is the recipient of several research and Best Paper awards, including the Friedrich Wilhelm Bessel Award by the Alexander von Humboldt Foundation and awards at the 2006 IEEE ICUWB, 2010 IEEE ICC, and 2011 and 2017 IEEE ISPLC. He is currently an Associate Editor for the IEEE Transactions on Communications, IEEE

Communications Letters and IEEE Communications Surveys and Tutorials, and has served as an Associate and a Guest Editor for several IEEE transactions and journals. He was General Chair of ISPLC '05, IEEE ICUWB '09 and IEEE SmartGridComm'13, and a Distinguished Lecturer of the IEEE Communications Society 2012-2013. He is a co-editor of the book Power Line Communications: Principles, Standards and Applications from Multimedia to Smart Grid, published by John Wiley & Sons in its 2nd edition in 2016.

#### Session 5: Standards and Applications

Mo5.1

#### A Light-Connected World

Harald Haas, University of Edinburgh, UK

We will start by clarifying the differences between visible light communications (VLC) and LiFi. This is followed by the introduction of the key building blocks required to create full LiFi networks. Next we report recent key achievements of the UP-VLC project with respect to component and demonstrator developments underpinning LiFi attocellular networks. We provide modelling results of such networks and address numerous misconceptions such as "LiFi is a line-of-sight technology". The talk also addresses the issue of energy efficiency of optical attocell networks and showcases how off-the-shelf solar panels can fulfill two functions at the same time, i) energy harvesting and ii) LiFi data detection. The talk closes by summarizing commercialization challenges.



**Prof. Harald Haas** holds the Chair of Mobile Communications at the University of Edinburgh, and is the Director of the LiFi R&D Centre. He is founder of pure LiFi Ltd. He first coined 'LiFi' in a TED Global talk in 2011. He gave a second TED Global talk in 2015. His talks have been watched online more than 4 million times. He has published more than 400 journal and conference papers, and his h-index is 62 (Google Scholar). Haas holds 43 patents. He holds a prestigious Established Career Fellowship from the EPSRC. In 2014, he was selected by EPSRC as one of ten RISE (Recognising Inspirational Scientists and Engineers) Leaders in the UK. He received the 'Outstanding Achievement Award' from the International Solid State Lighting Alliance (ISA)

in 2016. In 2017 he was elected Fellow of the Royal Society of Edinburgh.

#### Mo5.2

## **Optical Wireless Communication (OWC): IoT & Smart City Enabler**

Carsten Kausch, Audi China R&D

Optical Wireless Communication (OWC) offers big advantages as an enabler of IoT and smart city requirements. The biggest advantages and differences regarding the conventional communication are a) high-speed transmission b) small latency c) lighting-communication integration d) possible quantum encryption. OWC is an alternative solution towards the disadvantages and dead ends of 4G/5G/Wi-Fi networks, which obviously will be more and more problematic with IoT, Smart City and Big Data growth rates. Also the limited end of available cost relevant EM/RF bands finds OWC a much wider spectrum and higher data rates than the extension of RF towards GHz frequencies. On the other hand, the OWC's disadvantage of line of sight through diffuse media brings up the need of an infrastructure (ad hoc) network with further communication nodes. But this can technically be done, within a wider field of political and economic visionary supporters.

Furthermore the biological impact of OWC is natural like the sun light, except for ultraviolet or blue light, which can be filtered or just not be used. OWC offers "clean" and "low energy" solutions comparing to heavily discussed RF transmissions. As a costumer sustainable car manufacturer all these facts let Audi develop OWC prototypes for safe and convenient mobility.



**Mr. Carsten Kausch** studied at the Technical University Carolo Wilhelmina Braunschweig, Germany, with focus on dynamics and mathematics. After the university, he worked in the Claas Company as a development engineer for navigation and telematics for agricultural machine fleets. Since 1999, He has been working at Audi Electronics/Infotainment development, and invented 28 patents in the last 4 years for Audi China regarding China related technologies. He was a project leader for Audi AG electronic projects in early investment phases for MOST, DAB, BT, Hardware in the loop systems, R&D test robots, scalable software platforms, navigation simulation, mobile Internet applications etc, and is now an OWC project leader for Audi China R&D.

#### Standardization of Visible Light Communication in ITU

Dong Wei, University of Texas, USA

In July 2015, ITU-T Study Group 15 Question 18 (Q18) initiated a new project (called G.vlc) to study high-speed visible light communication (VLC) for in-premises applications. Q18 is developing three ITU Recommendations: (1) G.vlc-hs supporting a maximum data rate up to at least 1 Gbit/s; (2) G.vlc-ls supporting low-speed aplications; and (3) G.occ for optical camera communications. This series Recommendations specify the system architecture and functionality for all components of the physical layer and data link layer of VLC transceivers for in-premises applications designed for optical wireless transmission of data using visible light. Three operation modes are considered: unidirectional communication over the VLC link, bidirectional communication over the VLC link, bidirectional medium upstream such as Wi-Fi).



**Dr. Dong Wei** received the Ph.D. degree in Electrical Engineering from The University of Texas at Austin in 1998. From 1998 to 2000, he was an assistant professor with the Department of Electrical and Computer Engineering, Drexel University, Philadelphia, with research interests in signal processing for communications. From 2000 to 2006, he was a Principal Member of Technical Staff with SBC Labs (later becoming a part of AT&T Labs), with research interests in advanced access technologies. Since 2006, Dr. Wei has been a Senior Expert in Access Research with the U.S. R&D Center of Huawei Technologies Co., Ltd., with research interests in advanced access and home networking

technologies. He has been an active contributor in various standards developing organizations such as the ITU, IEEE, BBF, ATIS, and U.K. NICC.

#### Mo5.4

## **Standardization of Optical Wireless Communication in IEEE 802**

Qiang Li, HiSilicon, Huawei Technologies, China

Standardization activities of optical wireless communication has attracted increasing interest and participation in recent years. Currently, several standardization groups are working within IEEE 802 (LAN/MAN Standards Committee) with difference focuses and target applications. This talk will give an overview on various standardization activities within IEEE 802. This includes IEEE Std 802.15.7<sup>TM</sup>-2011, its ongoing revision IEEE Std 802.15.7<sup>TM</sup>, the new IEEE Std 802.15.13<sup>TM</sup> project and the 802.11 Topic Interest Group on Light Communication.



**Qiang Li** is a senior research engineer in Research Department of HiSilicon, Huawei Technologies, Ltd., Beijing. He received his B.S. degree from Beijing University of posts and Telecommunications in 2004 and his M.S. from Beijing University in 2007. He is currently leading a project on visible light communication. He has been actively involved in wireless standardization activities. He is the technical editor of IEEE 802.15.13<sup>TM</sup> and IEEE 802.11 Topic Interest Group on Light Communication.

# Visible Light Beacon System for Multimedia Applications

Shinichiro Haruyama, Keio University, Japan

"Visible light beacon system for multimedia applications" became an IEC (The International Electrotechnical Commission) international standard "IEC 62943" in March 2017. This talk will introduce its standard, concepts and possible use cases.



**Prof. Shinichiro Haruyama** obtained a Master's degree in Electric Engineering and Computer Science at University of California, Berkeley, USA and a Ph.D. in Computer Science at University of Texas, Austin, USA. He worked at AT&T Bell Laboratories (1991-) and Lucent Technology Bell Laboratories (1996) as researcher in USA. He then moved to Japan to work at Sony Computer Science Laboratories as researcher (1998-2002), served as visiting professor at Department of Information and Computer Science, Faculty of Science and Technology, Keio University (2002-2008) in Japan. Currently, he serves as

professor at Graduate School of System Design and Management, Keio University (2008-).

#### Mo5.5

#### Session 6: Devices and Systems

Mo6.1

#### Consideration on Transmission Characteristics of Optical Wireless Communication Systems

#### Mitsuji Matsumoto, Waseda University, Japan

With the increase of information transfer by the Internet, especially the increase of information transfer of high definition video information such as 4K and 8K, construction of ultra high speed information infrastructure network is demanded, and the construction of optical fiber network is spreading. In the 5G and IoT era, various applications, devices, and networks exist in recent years, and the presence of a high-speed access network that can seamlessly connect to an optical fiber network system becomes even more important. For this reason, an optical wireless communication system (OWC) capable of functionally coupling with an optical fiber system at high speed is promising, in particular, a free-space optical communication (FSO) system and a visible light communication system attract attention. Functional coupling of optical fiber, optical wireless and high speed radio wave wireless system is an increasingly important network technology for the upcoming 5G and IoT era and its development is expected. In this paper, development of an optical wireless system using a full optical connection technology that transparently connects FSO and single mode optical fiber without any conversion of optical signal is described. In optical wireless communication, the most important point for stably coupling spatial light to a single mode fiber is a high speed and high accuracy tracking method. Therefore, the relation between the tracking system and the atmospheric fluctuation that greatly affects the quality of the FSO system is described. Furthermore, the design examples of the used tracking technology, the results of the high-speed transmission experiment of the designed system, and the Radio on Fiber technology result of confining the wireless signal as it is in the optical fiber are mainly described.



**Prof. Mitsuji Matsumoto** engaged in research and development of telematics and multimedia systems at NTT Laboratories since 1970. From 1996 to 2015 he served as a professor at the Faculty of Science and Engineering, Waseda University. Currently he is a professor emeritus. He received his doctorate from Waseda University. Since 1980 he has conducted ITU standardization activities and contributed to the standardization of G4 facsimile and Multimedia services. During the 2001-2004 Study Period, he served as Vice Chairman of ITU-T SG16, who is in charge of research on multimedia, accessibility systems and terminals. Since 1990, he has been engaged in research on optical wireless communication, and has been engaged in designing and developing transceivers at the FSO now. Currently his

Membership is SMIEEE, IET, IEICE, IIEEJ.

#### Mo6.2

## **Diffractive Optical Elements for Visible Light Communication**

Huarong Gu, Tsinghua University, China

With light-emitting diode (LED) as its light source, visible light communication (VLC) is a potential solution to the next-generation communication technique with ultra-high speed. To achieve cellular network in VLC, the illumination area of each LED should be polygon. Meanwhile, wavelength division multiplexing (WDM) techniques can be employed to further increase the channel capacity when red, green, and blue (RGB) LEDs are used to form the white LED. Therefore, the illumination area of LEDs should be invariant to the incident wavelength to decrease interference within adjacent regions. In this talk, diffractive optical elements (DOEs) are utilized in the optical transmitter system of VLC to transform the diffraction patterns into desired shapes. A searching algorithm and an iterative algorithm are proposed for the design of one-dimensional and two-dimensional multicolor-oriented DOEs, respectively. The diffraction patterns for RGB LEDs with quasi-equal size and rather good uniformity are obtained. Double sampling Fresnel diffraction algorithm is developed to enlarge the diffraction patterns. The design accuracy of the DOE is also increased by a new modified GS algorithm.



**Dr. Huarong Gu** got his degrees of B.E. in 2004 and Ph.D. in 2010 both at Tsinghua University. During 2015-2016, he was a Visiting Scientist at Massachusetts Institute of Technology. He offers undergraduate courses "Micro-Optics" and "Optical Engineering Fundamentals". His research interests include optical information coding, optical data storage, and optical & mechanical system design. He presided over or participated in a number of projects funded by National Natural Science Foundation of China, National Key Basic Research Program of China, and National Important Scientific Instruments Development Program of China. He has published 32 research papers and owns 6 patents. He was awarded the First Prize of

Beijing Science and Technology Award in 2013, Jin Guofan Prize for Excellent Youth of China Instrument Society Scholarships in 2015, and Tsinghua University Education and Teaching Achievement Award in 2016.

#### Mo6.3

#### GaN-based LEDs for Visible Light Communication

Lixia Zhao, Institute of Semiconductors, Chinese Academy of Sciences, China

The rapid development of GaN-based LEDs has already stimulated its applications for general illumination. Beyond illumination, GaN-based LEDs can also be used for data communication, which achieves general lighting and optical wireless communication simultaneously. Compared with traditional radio frequency wireless communication, Visible Light Communications more secure, without electromagnetic interference or license restriction. It has also been considered as a potential access option for future 5G wireless communications. However, one of the major challenges is still the limited modulation bandwidth for LED devices. Here, the progresses of the GaN-based LEDs for light communication will be introduced. Besides the increase of the carrier concentration, the increase of the radiative recombination coefficient based on some nanostructures, such as SP-LEDs, RC-LEDs, to modify the photon surrounding environment will be discussed as well. These works will lay a foundation to further enhance the modulation bandwidth and optical power of GaN-based LEDs for light communication in free space.



Dr. Lixia Zhao received the Ph. D degree in physics from University of Nottingham, UK, in 2005. Afterwards, she worked at the GaN research Center of University of Cambridge till 2007. From 2007 to 2009, she worked in the Forge Europa, Co, Ltd, UK and was responsible for the development and quality of semiconductor lighting. In 2009, she joined the semiconductor lighting research & development center, institute of semiconductor, CAS with the "Import Outstanding Technical Talent Program" from CAS and was elected as youth innovation member of CAS in 2011. She has authored or co-authored over 80 papers with more than 2100 citations, and applied over 20 patents. Currently her research interests are mainly focused on the physical properties of III-Nitride semiconductor material and novel nanostructured devices.

#### Mo6.4

#### **ZnO-Based Ultraviolet Photodetectors**

## Kewei Liu, Changchun Institute of Optics, Fine Mechanics and Physics Chinese Academy of Sciences, China

Ultraviolet (UV) photodetectors have been widely used in various commercial and military applications, such as secure space-to-space communications, pollution monitoring, water sterilization, flame sensing and early missile plume detection, etc. The advantages in wide-band-gap (WBG) semiconductors, such as high radiation hardness and intrinsic visible/solar blind, have opened the possibility of developing high-performance WBG UV photodetectors, which are recognized as the potential alternative for the photomultiplier tube and Si-based photodetector.

Among WBG UV photodetectors, ZnO-based devices have received the special attention due to their good material properties: low defect density, easy fabrication, high radiation hardness, high carrier mobility, and environmental friendly. In addition, the alloying ZnO with MgO to make ZnMgO could continually increase the band gap from ~3.3 eV to ~7.8 eV, which allows the detection of UVA, UVB and UVC radiation. In our group, we have reported some interesting results in this field and I will talk about them in my presentation.



**Prof. Kewei Liu** received his B.S. degree in Chemistry from Northeast Normal University, Changchun, China, in 2003, and Ph.D. degree in Condensed Matter Physics from Changchun Institute of Optics, Fine Mechanics and Physics, Chinese Academy of Sciences, China, in 2008. From 2008 to 2009, he worked as a research fellow in Nanyang Technological University (NTU), Singapore. In 2009, he joined National Institute for Materials Sciences (NIMS), Japan, as a post doctor researcher. In 2013, he was selected as a candidate of the "One Hundred Talents Program" launched by the Chinese Academy of Sciences. And now he is a professor and Ph.D, supervisor in State Key Laboratory of Luminescence and Applications, at

Changchun Institute of Optics, Fine Mechanics and Physics, Chinese Academy of Sciences, China. His research interests are in the field of ZnO-based semiconductors and their optoelectronic devices. Up to now, he has published more than 50 SCI papers in "Appl. Phys. Lett.", "ACS Nano", "Adv. Funct. Mater.", "Mater. Today", etc.

#### Session 7: Atmospheric and Underwater OWC

Mo7.1

## High-speed Underwater Wireless Optical Communication: Potential, Challenges, and Possible Solutions

Mohamed-Slim Alouini, King Abdullah University of Science and Technology (KAUST)

Saudi Arabia

Traditional underwater communication systems rely on acoustic modems due their reliability and long range. However their limited data rates, lead to the exploration of alternative techniques. In this talk, we briefly go over the potential offered by underwater wireless optical communication systems. We then summarizes some of the underwater channel challenges going from severe absorption and scattering that need to be surpassed before such kind of systems can be deployed in practice. We finally present some of the on-going research directions in the area of underwater wireless optical communication systems in order to (i) better characterize and model the underwater optical channel and (ii) design, develop, and test experimentally new suitable modulation and coding techniques suitable for this environment.



**Prof. Mohamed-Slim Alouini** (S'94, M'98, SM'03, F'09) was born in Tunis, Tunisia. He received the Ph.D. degree in Electrical Engineering from the California Institute of Technology (Caltech), Pasadena, CA, USA, in 1998. He served as a faculty member in the University of Minnesota, Minneapolis, MN, USA, then in the Texas A&M University at Qatar, Education City, Doha, Qatar before joining King Abdullah University of Science and Technology (KAUST), Thuwal, Makkah Province, Saudi Arabia as a Professor of Electrical Engineering in 2009. Prof. Alouini is a Fellow of the

Institute of Electrical and Electronics Engineers (IEEE), a member of the Thomson ISI Web of Knowledge list of Highly Cited Researchers and of the Elsevier/Shanghai Ranking list of Most Cited Researchers, and an IEEE Distinguished Lecturer of the IEEE Communications Society. He is a recipient of the Recognition Award of the IEEE ComSoc Wireless Technical Committee in 2016 and a co-recipient of best paper awards in ten IEEE conferences (including ICC, GLOBECOM, VTC, PIMRC, and DySPAN). His current research interests include the modeling, design, and performance analysis of wireless communication systems.

#### Mo7.2

## Underwater Wireless Optical Communication: Where, When, and How?

#### Jing Xu, Zhejiang University, China

Recently, underwater wireless optical communication (UWOC) has gained a renewed interest from both academic and industrial communities. UWOC features sufficient bandwidth, high security and low time latency, and consequently offers many intriguing opportunities for a variety of applications such as broadband communication with seafloor sensors during a "fly-by" mission of an underwater vehicle, real-time video transmission, underwater sensor networks, etc. In this talk, we will review recent development of UWOC, especially the work carried out in Ocean College of Zhejiang University.



**Prof. Jing Xu** is an associate professor at Zhejiang University. He received his PhD in information engineering from the Chinese University of Hong Kong in 2011. His current research interests include underwater optical wireless communications, optical access technologies for submarine cabled observation systems, and innovative applications of submarine communications networks for ocean monitoring.

#### Mo7.3

#### **Recent Progress on the Optical Wireless Scattering Communication**

Chen Gong, University of Science and Technology of China, China

Optical wireless scattering communication can maintain certain communication rate even if the transmitter and receiver are not perfectly aligned. Due to the stronger scattering effect and low background radiation intensity, the scattering communication is typically performed in the ultraviolet spectrum. This talk will introduce our recent progress on the optical wireless scattering communication in the ultra-violet spectrum. After a brief introduction on the background, we present the work on the doubly-stochastic turbulence channel characterization based on the mixed Poisson model. Expectation-maximization algorithm are adopted to estimation the turbulence parameters, and it is shown that for the transmission distance of 1500 meters the coherence time can reach the order of several hundreds of milliseconds. Then we show the achievable security rate on the scattering communication in case of a legal receiver and an eavesdropper, where the transmitter can employ multiple UV LEDs for power shaping to maximize the achievable security rate. Non-jamming and cooperative jamming protocols are considered, and a tractable rule on the scattering communication, which can achieve 400kbps over 500 meters and 1Mbps over 1000 meters. Digital processing approaches and hardware implementations are briefly introduced.



**Prof. Chen Gong** received B.S. degree from Shanghai Jiaotong University in 2005, major in EE and minor in mathematics. He received M.S. degree in Tsinghua University in 2008, and Ph.D. degree in Columbia University in 2012. After graduation, he worked in Qualcomm as a senior system engineer until the end of 2013. In January 2014, he joined Optical Wireless Communication and Networking Center in the University of Science and Technology of China. His interests span from theoretical research in wireless communication, wireless optical communication, and the related signal processing, both in theoretical research and prototype development. His publications include IEEE Transactions papers, U.S. and China patents, and RAN-1 standard contributions. He has been awarded by "China Young 1000 Program" in 2015, and Hongkong Qiushi

Outstanding Young Researcher Award in 2016.

## A LDPC Code for Non-line-of-sight Ultraviolet Communication

#### Yong Zuo, Beijing University of Posts and Telecommunications, China

First, a generalized received response model considering both scattered propagation and random detection is presented to investigate the impact of inter-symbol interference (ISI) on link data rate of short-range non-line-of-sight (NLOS) ultraviolet communication with photon multiplier tube (PMT). Good agreement with the experimental results by numerical simulation is shown. Based on the received response characteristics, a heuristic check matrix construction algorithm of low-density-parity-check (LDPC) code is proposed to approach the data rate bound derived in a delayed sampling (DS) binary pulse position modulation (PPM)system. Compared to conventional LDPC coding methods, better bit error ratio (BER) can be achieved for short-range NLOS UVC systems.



**Prof. Yong Zuo**, Associate Professor with State Key Laboratory of Information Photonics and Optical Communications, Beijing University of Posts and Telecommunications (BUPT), China. He received his B.S. and M.S. degrees in electromagnetic field and microwave technology from BUPT, and his Ph.D. degree in electronic engineering from Queen Mary, University of London (QMUL), UK. His current research interests include optical wireless communication, optical networking and optimization, Near Field Communication (NFC).

#### Mo7.5

## Techniques for Atmospheric Optical Communication Channel Monitoring and Link Availability Forecasting

Haiping Mei, Anhui Institute of Optics and Fine Mechanics

Chinese Academy of Sciences, China

It is well known that, the optical wireless communication (OWC) link has great probability to be disturbed or interrupted by the atmospheric channel. So it is a key problem to get knowledge of the atmospheric channel's optical properties as well as their effects on light beam propagation for the optimal designation and performance estimation of optical terminals. The real time monitoring of atmospheric channel in company with the short time forecasting of link availability are of critical importance for establishing a high stability optical link from the satellite to ground with the configuration of multi station diversity. In the report, the theory and software for estimating the effects of laser beam propagation through atmosphere, and the preliminary theory for modeling and calculating the geostationary satellite-to-ground laser communication link availability are introduced. And then, the concept and basic components needed to construct an atmospheric monitoring and forecasting system are proposed and described. In the end, some of the welldeveloped instruments or techniques by Anhui Institute of Optics and Fine Mechanics for measuring the whole layer atmospheric optical parameters such as the coherence length, transmittance and background radiation are introduced .It is worth to note that take full advantage of the progresses in the area of atmospheric optics is essential to promote the performance of optical wireless communication systems.



**Prof. Haiping Mei** was born in 1980 and received his B.S. degree at the department of physical education from Anhui Normal University in 2001. After that time, he devoted in the research of the properties and measurement techniques for atmospheric optical turbulence as well as its influence on the propagation of laser beam from satellite to the ground. He received the M.S. degree and Ph.D. degree in 2004 and 2007 respectively in the field of atmospheric physics and atmospheric environment from the Hefei Institutes of Physical Sciences, Chinese Academy of Sciences (CAS) and worked there until today. He is now an associate professor and master supervisor.

He has been honored the membership of Youth Innovation Promotion Association, CAS. The main contribution of him to science is to invent an advanced Fiber Optical Turbulence Sensing System for measuring the strength and spatial structure of atmospheric optical turbulence and to take many experiments for uncovering the temporal and spatial properties of optical turbulence near ground, off shore and on the open sea. His research interests also include the large aperture telescope side selection and the monitoring and forecasting of atmospheric channel for satellite-to-ground optical communication. He has authored or co-authored over 30 publications in peer reviewed journals and 4 China patents of invention.

#### Session 8: OWC for Future Applications

Mo8.1

#### Augmented Data Centers Network by Optical Wireless Links

Shlomi Arnon, Ben-Gurion University of the Negev, Israel

A data center is a physical or virtual group of thousands servers, for the searching, storage, managing and distribution of information, which consume huge amount of energy. DC includes servers, routers, switches and other communication and storage equipment as well as a support system including an air conditioning system and electricity regulator units. Datacenter operators face with the challenges of meeting exponentially grows in the demands for network bandwidth without unreasonable growths in operation and infrastructure cost. In order to meet the requirements of moderate increase in operation and infrastructure cost technology revolution is required. One way to overcome these challenges is using augmented network based on fiber together with optical wireless communication (OWC) or free space optics (FSO). The OWC link could be deployed on top of the existing cable/fiber network layer, such that live migration could be done easily and dynamically. In that case the network topology is flexible and adapts quickly to changes in traffic, heat distribution, power consumption and characteristics of the applications. In addition, OWC could provide an easy way to maintains and scale up data centers.



**Prof. Shlomi Arnon** is a Professor at the Department of Electrical and Computer Engineering at Ben-Gurion University (BGU), Israel. Professor Arnon's honors and awards include SPIE Fellow and Fulbright Fellow. During 1998-1999 Professor Arnon was a Postdoctoral Associate (Fulbright Fellow) at LIDS, Massachusetts Institute of Technology (MIT), Cambridge, USA. His research has produced more than eighty journal papers in the area of optical, satellite and wireless communication. During part of the summer of 2007, he worked at TU/e and PHILIPS LAB, Eindhoven, Nederland on a novel concept of a dual communication and illumination system. He was visiting professor during the summer of 2008 at TU Delft, Nederland.

During the year 2011-2012 he took sabbatical leave at the Silicon nano photonic Lab, Cornell University, USA. He is/was an associate editor for the Optical Society of America - Journal of Optical Networks in 2006, and the IEEE Journal on Selected Areas in Communications for a special issue on optical wireless communication in 2009 and 2014. He is co-author of the book Applied Aspects of Optical Communication and LIDAR, Taylor & Francis/ CRC, 2010 a co-editor of the book Advanced Optical Wireless Communication Systems, Cambridge University Press, 2012 and editor of the book Visible Light Communication Cambridge University Press, 2015.

#### Mo8.2

## Real-time Visible Light Communication System based on Phosphor Coated Blue LED

Xiong-Bin Chen, Institute of Semiconductors, Chinese Academy of Sciences, China

The bandwidth expanding technology of visible light communication system based on phosphor coated blue LED has been proposed. 610Mbps real time visible light communication demo system and the symmetrical 100Mbps VLC ethernet system have been demonstrated using the phosphorbased LED.



**Prof. Xiong-Bin Chen** received his B.E. degree in Optoelectronic Technology from East China Normal University, Shanghai, China, in 1996. He received his M.S. degree in Communication and Information System from National University of Defence Technology, Changsha, China, in 2001. He received his Ph.D. degree in Microelectronics and Solid Electronics from Institute of Semiconductors, Chinese Academy of Sciences, Beijing, China, in 2007. He worked as a teacher in Hunan University, china, from 1996 to 2004. He worked as a researcher in Institute of Semiconductors, CAS from 2007 to the present. In 2015, he was promoted as a professor in Institute of Semiconductors, CAS. He began his

research works on optical interconnection in 2004. His group focused on visible light communication in 2009. Their two demo VLC systems were exhibited in Shanghai World Exposition 2010. They pushed up the real time data rate of phosphorescent LED to 610Mbps in 2015.

## Connected Lights: Paving The Way for User-Centric Design

Rong Zhang, University of Southampton, UK

In this talk, we introduce the user-centric design principle for VLC, where three key aspects are identified and elaborated on, namely 1) signal quality, 2) system control and 3) service provision. More explicitly, the concepts of amorphous cell formation, separated Up-Link (UL) and Down-Link (DL) and decoupled data and control etc, all demand radically new thinking. We provide design examples to show the benefits of user-centric VLC design for enhanced coverage, capacity and mobility, through the interplay between positioning, communications and networking. We believe that the advocated user-centric VLC design is of key significance in the small-cell scenarios of future (optical) wireless communications.



**Prof. Rong Zhang** (M'09, SM'16) is an Assistant Professor in Southampton Wireless group within the school of ECS at University of Southampton (UoS). He is also the RAEng industrial fellow with British Telecom (BT), leading 5G-Home laboratory. He has held various prominent positions in both academia and industry. He has a total of 80+ IEEE/OSA publications, including 55+ journals (20+ as first author). He regularly serves as reviewer/editor for IEEE/OSA journals and funding bodies and has been several times as TPC member/invited session chair of major conferences. His research covers a range of topics in (optical) wireless communications, from signal processing to network optimisation.

#### Mo8.4

#### **Optical Wireless Communications Technology Based Internet of Things**

Xuan Tang, Fujian Institute of Research on the Structure of Matter, CAS, China

The Next Generation Communication Technologies (NGCT) market is a rapidly growing with the use of smart mobile phones and other electronic devices. This trend will continue with growing population economy and the emergence of cloud, big data, AI, Internet of thing. Current communication technologies based on the radio frequency (such as 4G, WiFi, may not be able to offer the capacity to fulfil the need for future high-speed data communications. Once possible alternative and complementary technology is the optical wireless communications (OWC) for the future NGCT market. OWC many attractive features such unlicensed wide bandwidth, no susceptible to radio frequency interference, and the potential of spatial reuse of the carrier frequency in adjacent communication cells, room, building. The potential synergy of illumination, data transmission, and indoor localization functionalities using a simple light emitting diode based light source(s) has stimulated numerous research and development activities at a global level. The group is actively engaged in research in OWC with currently as many as 20 collaborative research projects funded by both industry and government. The project includes optical wireless sensor network for medical applications, a high accuracy indoor positioning system, OWC for smart homes, audio conferencing, and remote video signal transmission for outdoor LED screens.



Dr. Xuan Tang is an academic leader and Professor at the Fujian Institute of Research on the Structure of Matter, Chinese Academy of Sciences (CAS) since Oct. 2014. She is a team member of Youth Innovation Promotion Association CAS. Her research interests are in the areas of optical wireless communication systems including high speed infrared/ultraviolet laser communications, visible light communications and optical MIMO systems, as well as RF communication technologies. In June 2008 she was awarded BEng (1st Class with Hons.) in Electronic and Communications Engineering from Northumbria University, Newcastle, UK. In 2013 she obtained her PhD on Polarisation

Shift Keying Modulated Free-Space Optical Communication Systems, and it was in collaboration with Chosun University, South Korea. From Oct. 2012 to July 2014, she worked as the Postdoctoral Researcher at the Department of Electronic Communications Engineering, Tsinghua University. The research group that she leads has obtained over 20 funding, including General Financial Grant from China Postdoctoral Science Foundation, National Science Fund for Young Scholars, External Cooperation Program of Chinese Academy of Sciences, Youth Innovation Promotion Association CAS, Returned Overseas Chinese Scholars of the State Education Ministry and so on, the grant of which is as much as ten-million RMB. The group has also published over 100 papers. She has been invited to be the session chair for top international conferences, and also acts as a reviewer for a number of high impact journals including IEEE J. of Light wave Technology, IEEE J. Selected Areas in Communications, IET Communications, Applied Optics etc. She is IEEE member.

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