Tutorial T-15: Optical Wireless Communications

Presenters: Maite Brandt-Pearce (University of Virginia, USA), Zhengyuan Xu (University of Science and Technology of China, China), Steve Hranilovic (McMaster University, Canada)

Tutorial Overview

As the radio frequency spectrum congests, the optical medium provides an attractive alternative, supplying ample and easily-reusable spectral resources. Optical wireless communications that use light to carry information through a tetherless channel can offer Gbps connectivity to wireless users. This tutorial covers the essential characteristics of optical wireless systems to provide communications engineers the ability to work within this exciting field. State-of-the-art system design, performance, and applications are described. The tutorial will cover a range of theoretical and practical aspects of optical wireless communications including indoor and outdoor links:

Outline of applications: We will begin with an outline of the range of applications of optical wireless communications. This will emphasize the two best known areas – indoor optical wireless and free space optics (FSO) but will also mention other applications such as chip interconnect, satellite and deep space communications, and underwater communications. A summary of key potential advantages and drawbacks of an optical wireless approach compared with other techniques will be given.

Introduction to optical transmitters and receivers: We will next describe the components of typical optical communication systems. The properties of both lasers and LEDs as optical transmitters will be described in detail. The photodetectors used in receivers will be described and the difference between direct detection and coherent reception discussed. The differences between imaging and nonimaging receivers will be discussed and the importance this has in MIMO applications. The important noise mechanisms in optical wireless systems will be described.

Performance metrics and modulation techniques: Many of the metrics routinely used in RF wireless communications are not directly applicable or are not useful. This section will discuss the key factors in measuring the performance of optical wireless systems. Because of the different characteristics of optical systems, modulation techniques developed for RF systems are not useful or are not optimum. The key modulation techniques for optical wireless communications will be introduced and their characteristics described.

Free Space Optical Communications: Important aspects of FSO will be introduced. We begin by presenting models of the lineof-sight atmospheric channel under various weather conditions. We review the requirements and impact on system performance of the acquisition, pointing and tracking (APT) subsystem. Challenges and benefits that can be obtained by using multiple transceivers in a MIMO configuration will be explored. Recent developments and current areas of research will be discussed.

Visible Light Communications: The introduction of lighting LEDs has created a new opportunity to create very high data rate wireless systems. In this section an up-to-date overview of research on indoor visible 2 light communications will be provided. Other emerging applications such as vehicle to vehicle communications will be described.

Experimental techniques and challenges: There have been a number of recent papers describing experimental work on all aspects of optical wireless communications. From the communications viewpoint, the most critical part for system level design and testing is the unique sounding and

measurement techniques for optical wireless channels, including channel impulse response, path loss, large-scale and small-scale signal fading statistics. These metrics may vary from indoor to outdoor scenarios. This section will describe some key recent experiments and measurement techniques to better capture channel characteristics, and in some cases particle-wave dual properties. Analytical and experimentally validated models will be presented. Then communication system performance measurement techniques will be covered. Implementations of data modulation/demodulation, coding/decoding, pre-/postprocessing of transmitted and received signals will be introduced, followed by some key challenges.

Question and Answer Session and Discussion of the Key Research Challenges: The tutorial will conclude with a question and answer session and a panel discussion by the three presenters of what they consider the key research challenges in optical wireless communications.

Presenter Biographies

Maïte Brandt-Pearce received her Ph.D. in Electrical Engineering from Rice University in 1993. She then joined the Charles L. Brown Department of Electrical and Computer Engineering at the University of Virginia, where she is currently a full Professor. Her research interests include nonlinear effects in fiber-optics, free-space optical communications, 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 serves on the editorial board of IEEE Communications Letters, IEEE/OSA Journal of Optical Communications and Networks, and Springer Photonic Network Communications. She is co-editor of a book entitled Cross-Layer Design in Optical Networks, Springer Optical Networks Series, 2013. She was the General Chair of the Asilomar Conference on Signals, Systems & Computers in 2009. Dr. Brandt-Pearce has over a hundred and fifty major journal and conference publications.

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. He is Founding Director of the Optical Wireless Communication and Network Center and a chief scientist of the National Key Basic Research Program (973 Program) of China. His research focuses on wireless communication and networking, optical wireless communications, geolocation, intelligent transportation, and signal processing. He has published over 180 journal and conference papers. He has served as an Associate Editor and Guest Editor for different IEEE journals, and serves as Associate Editor for the OSA/SIOM journal *Photonics Research* and Guest Editor for IEEE JSAC - Special Issue on Optical Wireless Communications. He was a Founding Chair of IEEE Workshop on Optical Wireless Communications and an elected member of IEEE Signal Processing Society's Technical Committee on Signal Processing for Communications for several years.

Steve Hranilovic received the B.A.Sc. degree with honours in electrical engineering from the University of Waterloo, Canada in 1997 and M.A.Sc. and Ph.D. degrees in electrical engineering from the University of Toronto, Canada in 1999 and 2003 respectively.
He is currently an Associate Professor in the Department of Electrical and Computer Engineering, McMaster University, (Hamilton, ON, Canada), where he also serves as Associate Chair for

undergraduate studies. During 2010-2011 he spent his research leave as Senior Member, Technical Staff in Advanced Technology for Research in Motion, Waterloo, Canada. His research interests are in the areas of free-space and wired optical communications, digital communication algorithms, and electronic and photonic implementation of coding and communication systems. He is the author of the book *Wireless Optical Communications Systems* (New York:Springer, 2004).
Dr. Hranilovic is a licensed Professional Engineer in the Province of Ontario and was awarded the Government of Ontario *Early Researcher Award* in 2006. He is a founding Chair of the annual *IEEE Workshop on Optical Wireless Communications* and currently serves as an Editor for the *IEEE Transactions on Communications* in the area of Optical Wireless Communications.