VISIBLE LIGHT COMMUNICATIONS: THE ROAD TO STANDARDIZATION AND COMMERCIALIZATION (PART 2)

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Visible light communications (VLC) has a long history dating back to ancient signal fires, followed by the 1880 Alexander Graham Bell photophone, which transmitted speech wirelessly using modulated reflected sunlight. But it was the emergence of solid state light sources that sparked the imagination of researchers, such as those at Nakagawa Laboratories at Keio University around the turn of the 21st century, to demonstrate that solid state light sources could be used for secondary purposes such as data transmission and positioning.

Since the early days of VLC there has been much research demonstrating increased unidirectional data rates, with increasingly sophisticated modulation formats, today approaching 1 Gb/s. And over this same timeframe we have seen several VLC standards generated specifying data rates approaching 100 Mb/s. However, over this same timeframe we have also seen several RF wireless standards, such as WiFi, Bluetooth, and ZigBee, developed and deployed in numbers that far exceed those for their comparable VLC counterparts. So what are the issues associated with the mass deployment of VLC technology?

Comparing the deployment of VLC vs., say, WiFi, one can observe that the VLC ecosystem is more complex. If we assume that today's platform of choice is the mobile device, than we can see that the user device is in one ecosystem and the transmitting LED lighting device is in another ecosystem; that is, the folks who make mobile devices are waiting for a large percentage of the lights to be modulated before they deploy VLC in the handset, while the LED lighting industry is waiting for the reverse complementary situation. Additionally, modulating LED lights will result in additional complexity that is hard to justify without being able to realize a return on the investment. Contrast this with the more cohesive WiFi ecosystem where, even during the early days of emerging deployment, one company could supply devices for both the base station and the client.

One could argue that trying to disrupt an established RF solution such as WiFi is a daunting task at best, especially if there are overlapping data rates and services. There is an argument to be made that VLC offers spectral relief, but so far the RF industry seems satisfied to rally around the concept of RF small cells to increase deployment density. Could it be that what is needed to kick-start the market is a usage (e.g., killer app) that provides a unique offering, at a very low cost, that is not readily available from an existing wireless solution; a usage that can bridge across the two ecosystems to stimulate VLC deployments? The inherent advantages of VLC deployments are most strongly realized in applications such as secure small cell communications and low-cost short-range links (e.g., for interactive toys). Visible light communications would have beneficial characteristics in high-accuracy, low-interference, automobile communication, and positioning systems. In addition, accurate indoor positioning as well as the potential for localized high-rate "data showers" may serve as key motivators of VLC going forward.

This Feature Topic in Visible Light Communications captures recent progress in the development, standardization, and commercialization of VLC technologies. A key aim of this issue is to provide an overview of current research and identify areas for future development to support emerging applications of VLC technologies. The articles in this Feature Topic are the second part, which were spread over two issues of *IEEE Communications Magazine*, with the first part published in December 2013.

The first article, "An Illumination Perspective on Visible Light Communications" by Tsiatmas *et al.*, discusses joint illumination and communication systems. The article points out that the wide acceptance of VLC systems will not only depend on the advancements in the achieved transmission rates, but also on their ability to comply with the illumination requirements since the transmission of data does not come free.

The second article, "Connecting Networks of Toys and Smartphones with Visible Light Communication" by Corbellini *et al.*, shows how VLC can combine illumination, wireless communication, and play with connected toys, and all at low cost using components readily available in many toys. The article points out that one of the key challenges is combining the different protocols without increasing the cost.

In "Rapid Prototyping of Standard Compliant Visible Light Communications System" by Gavrincea *et al.*, the authors discuss the use of the IEEE 802.15.7 standard as a starting point to develop commercial VLC applications and offer a flexible platform where the introduction of new features can be achieved without requiring long development times.

The fourth article, "Image-Sensor-Based Visible Light Communicatioalsons for Automotive Applications" by Yamazato *et al.*, introduces an image-sensor-based VLC intended for automotive applications, in which the image sensor can provide not only VLC functions but also safety applications using image or video processing technologies.

In the final article, "VLC: Beyond Point-to-Point Communication" by Serafimovski *et al.*, the authors present VLC as a unique and viable alternative to RF indoor communication strategies and discuss a plethora of application scenarios for future systems such as the concept of VLC small cells to deliver wireless data while offering indoor security advantages.

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BIOGRAPHIES

STEVE HRANILOVIC [S'94, M'03, SM'07] (hranilovic@mcmaster.ca) received his B.A.Sc. degree with honours in electrical engineering from the University of Waterloo, Canada, in 1997, and his 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, Ontario, Canada), where he also serves as the Associate Chair for Undergraduate Studies. During 2010–2011 he spent his research leave as a senior member of technical staff in Advanced Technology for Research in Motion, Waterloo, Canada. His research interests are in the areas of free-space and optical wireless communications, digital communication algorithms, and electronic and photonic implementation of coding and communication algorithms. He is the author of the book *Wireless Optical Communication Systems* (Springer, 2004). He is a licensed Professional Engineer in the Province of Ontario and was awarded the Government of Ontario Early Researcher Award in 2006. He currently serves as an Editor for *IEEE Transactions on Communications* in the area of Optical Wireless Communications, and is a founder and current Co-Chair of the annual IEEE Workshop on Optical Wireless Communications.

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