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William Shieh talks with *ScienceWatch.com* and answers a few questions about this month's Fast Moving Front in the field of Physics.

Article: Coherent optical orthogonal frequency division multiplexing
Authors: Shieh, W;Athaudage, C
Journal: ELECTRON LETT, 42 (10): 587-589 MAY 11 2006
Addresses: Univ Melbourne, ARC, Special Res Ctr Ultrabroadband Informat Networks, Dept Elect & Elect Engn, Melbourne, Vic 3010, Australia.
Univ Melbourne, ARC, Special Res Ctr Ultrabroadband Informat Networks, Dept Elect & Elect Engn, Melbourne, Vic 3010, Australia.

SW: Why do you think your paper is highly cited?

For the first time in "open access" literature, this paper introduced a novel modulation format which combines two powerful techniques in optical communications, coherent detection, and orthogonal frequency-division multiplexing (OFDM).

This new modulation format called coherent optical OFDM (CO-OFDM) holds the promises of delivering high electrical and optical spectral efficiency, receiver sensitivity, and optical dispersion resilience. As such, CO-OFDM has emerged as one of the attractive candidates for the forthcoming 100 Gb/s and 1 Tb/s Ethernet transport.

SW: Does it describe a new discovery, methodology, or synthesis of knowledge?

It describes a new approach of combating optical chromatic dispersion (CD) and polarization mode dispersion (PMD) in optical communications. Independently from other research groups in Monash University, Australia, and the University of Arizona in the USA, who looked at the problem from an optical direct-detection side, we applied coherent optical OFDM to long-haul optical communications, which presents an exciting potential for future ultrahigh-speed optical networks.

SW: Would you summarize the significance of your paper in layman's terms?

Internet traffic has been growing at an alarming rate of 40-50% per annum. This places significant strain on the underlying communication infrastructure, which is predominately based on fiber optical transport. The line rate of the optical signal has increased from 2.5 Gb/s to 40 Gb/s in the last decade, and now 100 Gb/s is the speed being asked for by carriers and developed by suppliers.

However, the ultrafast optical signals are very sensitive to the optical dispersion in the fiber, and subsequently managing the dispersion to allow for 100 Gb/s has become a difficult problem. The analogy can be made between this phenomena and a Formula 1 car race, a small bump on the track can easily wreak havoc on a highly specified and fast moving race car.

> *"Our society has entered an information age that is heavily centered around the internet. As such, it is imperative that the underlying infrastructure is able to meet the demands from the relentless internet growth stemming from bandwidth-rich applications such as YouTube and Internet Protocol Television (IPTV)."*

OFDM provides a smart solution to this problem. In layman's terms, it is a "divide-and-conquer" strategy. OFDM partitions the entire channel into many small segments. Even though the optical channel is relatively uneven in its entirety, each segment is quite smooth and flat, and subsequently can be managed relatively easily. It is the same reason why OFDM has been very successful in wireless communications.

There is one more piece of the puzzle that needs to be uncovered in order to apply OFDM in optical systems. OFDM consists of many orthogonal subcarriers, each essentially an oscillating wave with its amplitude swinging up and down between positive and negative values. One of the stumbling blocks to apply OFDM is that conventional optical communication systems are based on intensity modulation which, by nature, is positive. This makes application of OFDM unnatural, with inherent sacrifices to either optical power efficiency or spectral efficiency.

This is where the advantages of coherent detection come into play; with coherent detection, both positive and negative signal amplitudes are permitted. However, coherent detection has more components and thus is more costly.

Fortunately, coherent detection enables dual polarization transmission, doubling the capacity and thus alleviating the cost-disadvantage. Furthermore, dual polarization transmission completely overcomes the polarization mode dispersion impairment, which has been considered as the fundamental barrier for ultrafast optical communications.

The introduction of CO-OFDM could prove opportune, as the required digital signal processing power can be provided either today, or in the near future, by the rapidly advancing powerful silicon technology underpinned by the well-known Moore's Law.

SW: How did you become involved in this research, and were there any problems along the way?

I have performed extensive research in optical communications for 16 years. I have been doing research with my Ph.D. students on coherent optical communications for the last five years. At the time, the finite-impulse-response (FIR) filter and the Viterbi-type Maximum-Likelihood Sequence Estimator (MLSE) were two approaches we were studying to mitigate the optical dispersion.

I was frustrated with the computation complexity of both FIR filters and Viterbi decoders. In a casual conversation with one of my colleagues in our department, Dr. Chandra Athaudage (the other co-author of the paper), he mentioned to me that he was working on OFDM, which was a popular modulation technique to combat multipath interference in wireless systems.

I began to study the OFDM literature, and felt that I had found the solution for the optical problems at hand. I laid out the necessary equations and ran several simulations, and found the results were quite impressive. These were later submitted to *Electronic Letters*.

In the field of optical communications, experimental demonstration is always regarded as a premium. We embarked on the first proof-of-concept experimental demonstration for CO-OFDM. It turned out to be one of the most difficult experiments I have ever attempted.

CO-OFDM is quite a complicated system involving non-trivial experimental configurations and signal processing. At the beginning, we tried very hard and could not recover the CO-OFDM signal properly. My students and I were constantly pondering about whether CO-OFDM simply did not work, or whether we simply had some bugs in the hardware or software. There were many times we thought we ran into a dead end and came very close to the conclusion that CO-OFDM was just a theoretical fantasy.

Finally, we triumphed and managed to demonstrate a multi-Gigabit CO-OFDM transmission. Luckily we were not alone in the demonstration game. After our first CO-OFDM demonstration, progress has been accelerated by tremendous efforts from other institutions such as Monash University in Melbourne, Australia (with direct-detection optical OFDM); Japan's KDDI R&D Laboratories and Nippon Telegraph and Telephone Corporation's (NTT) Photonics Laboratories, along with Alcatel-Lucent's Bell Labs in Stuttgart, Germany and New Jersey, USA, who are all in a friendly race to outstrip each other with better results. Many "heroic" experiments in optical communications are produced by using CO-OFDM.

SW: Do you foresee any social or political implications for your research?

Our society has entered an information age that is heavily centered around the internet. As such, it is imperative that the underlying infrastructure is able to meet the demands from the relentless internet growth stemming from bandwidth-rich applications such as YouTube and Internet Protocol Television (IPTV).

There is a great concern for the sustainability of such explosive growth in a cost-effective manner. Emerging new technologies such as CO-OFDM provide an important step in the right direction for the next generation of optical networks by facilitating higher spectral efficiency and dynamic bandwidth provisioning, in order to reduce the overall installation and maintenance costs.

William Shieh, Ph.D.
Associate Professor and Reader
Department of Electrical and Electronic Engineering
The University of Melbourne
Victoria, Australia

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