

A Snapshot of

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MUNICATIONS

OFC/NFOEC chairs

The field of optical communications is advancing at nearly the speed of light. This preview of March's Optical Fiber Conference/National Fiber Optic Engineers Conference (OFC/NFOEC) describes current trends, including the increasing role of wireless technologies, the continued integration of optical networking with other networking layers, and the entry of optical interconnects into the computercom era.

The recent award of the Nobel Prize in Physics to Charles Kao—who is widely regarded as the father of fiber-optic communications—underscores the tremendous changes that optical fiber has brought about in modern society. Fiber optics has revolutionized the way we receive information and communicate with one another, and it has played a major role in ushering in the Information Age. The field continues to advance rapidly, as measured by deployed capacity, the technology being deployed, the systems under development and the research results being released.

The largest forum in optical communications is OFC/NFOEC, which will be held March 21-25, 2009, in San Diego, Calif., U.S.A. This article includes contributions from the OFC/NFOEC program sub-committee chairs, program chairs and general chairs. Based loosely on the conference program, it describes the current state of optical communications as well as promising future developments in quantum communications, interconnects for short-distance data communications, core networking, “green” photonics and other areas. For more information about OFC/NFOEC or to register, visit www.ofcnfoec.org.

Market Overview

From a top-down market perspective, the most important trend has been a blurring of boundaries between telecom, datacom and the adjacent information industries, as well as the border between wireline and wireless. Traditional services and providers are facing competition with non-traditional providers and technologies—for example, voice service vs. Skype. Telecom providers continue to penetrate services such as pay TV and hosted IT for both enterprises and consumers.

Vast data centers are being located in regions with inexpensive electricity, placing new requirements on the communication links feeding them. This year's Service Provider Summit, which takes place on March 24, will feature a keynote talk by Vijay Gil from Google, followed by a session about how leading edge communications needs are affected by new “super”-data centers. Some of the participating data center entities are traditional ISP and network operators, while others are large enterprises serving their internal needs, hosting specialists, application providers and content delivery network providers.



The mega data centers require high capacity at all length scales, from long-haul to computer interconnects. The number of optical interconnects in a single high-performance computing system will grow dramatically, opening a huge new market for optical communications vendors.

After several technology trials of 100-Gb/s transmission across the world, and availability of standards and systems supporting 100 Gb/s, integration and economic feasibility are becoming highly relevant topics for carriers and system vendors. Economic feasibility will be addressed by Ross Saunders from Opnext, Inc.

Technology

Optical transport networks (OTN) have evolved from a static legacy SONET/SDH-based transport to a dynamic intelligent next-generation OTN (NG-OTN) with improved operational efficiency and more cost-effective transport than the existing ring-based infrastructure. There is growing customer demand for more bandwidth, faster provisioning and richer sets of service functionality. New equipment is available that features a high degree of functional integration and is capable of supporting an embedded intelligent control plane.

Advanced optical networks that include new technologies such as the reconfigurable optical add/drop multiplexer (ROADM), wavelength-selective switches and fully tunable optics are entering service. The technology is also evolving to support migration towards IP and OTN convergence at the bearer and control plane layer. Researchers have demonstrated maturity, stability and interoperability of GMPLS-based control plane protocols.

Kathy Tse (AT&T) will provide a detailed review of the expected features and applications of the NG-OTN, and

Michael Reina (Telcordia) will discuss how the management plane (e.g., OSS) may be leveraged to speed deployment of the control plane in real-world network environments.

Service providers are experiencing growing demand for access bandwidth, fuelled by demand for HDTV, multimedia Internet entertainment and other Internet applications. Vincent O'Byrne (Verizon) and Rajesh Yadav (Verizon) will discuss their experiences with fiber technology deployment in the access network and ways to achieve overall cost efficiency.

Recent technology developments have accelerated the availability of 100G transmission technology for long-haul DWDM networks. Erwan Pincemin (France Telecom), Ted Schmidt (Opnext), and Marco Camera (Ericsson) will discuss deployment of high-speed (40/100G) systems in metro and core networks.

Non-Traditional Application

Scientists are making progress in non-traditional areas of optical communication such as visible light communications and optical interconnects. Visible light communications are not a replacement for optical communications associated with the infrared part of the spectrum; rather, they are a convenient addendum that could be very useful for short-range applications. Shin-ichiro Haruyama will discuss recent progress.

High-speed optical interconnects are attracting much interest in the industry. The integration of silicon photonics is the most promising technology for these applications. Invited talks and tutorials on topics related to high-speed interconnects will be given by Petar Pepeljugoski, David Miller and Vladimir Stojanovic.

The capacity of optical routers is advancing. Jurgen Gripp will describe a terabit optical router, while Vincent Chan will

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discuss optical flow switching. As we move towards a “smart Internet” that serves as a comprehensive distribution and peer-to-peer communication channel to all, speed, reliability, power consumption and content delivery all come to the same basket. Ioannis Tomkos will lead a workshop exploring the concept of dynamic converged optical networking.

Optical Interconnects for the Computercom Era

In the 1970s and 1980s, optical fibers entered the long-haul markets. Similarly, a new optical revolution is coming to computer systems. The major motivations remain the same: The copper cables connecting racks, boards and chips are too slow and power-hungry for the growing capacity—which already exceeds multi-Tb/s. Optical fibers are already starting to connect racks in supercomputer systems and large data centers. In just three to five years, a single high-performance computing system may require well over one million optical interconnects, opening a huge new market for optical communication vendors.

On a longer time scale, high-performance processing will require hundreds to thousands of cores per microprocessor, which is beyond the capability of current architectures due to limitations imposed by electrical interconnects. One of the primary challenges is the extreme need for low-energy wideband interconnects packaged in a low-cost photonic module.

The cost/bit and power/bit targets become extremely aggressive for computercom: 10 percent or less of that found in traditional datacom transceiver technology. A reduction of more than 100 times in cost/bit is required for ultra-short-reach on-chip optical interconnects. New multi-Tb/s transceivers must therefore be developed.

In the computercom symposium, speakers from system companies will detail the requirements of ultra-short-reach optical links for future computer systems at all levels. Speakers from datacom transceiver companies will discuss the capabilities of today’s optical modules and prospects for scaling current devices and packaging into the future. Finally, speakers from the research community will discuss the potential of emerging technologies that offer the promise of enabling massive amounts of short-reach interconnect bandwidth at low cost, with low power consumption, a high area density and the potential for future scalability.

Quantum Communication

Quantum communications in optical fiber providing photonic layer “future-proof” security has seen remarkable progress in range, domains of use and our understanding of the transmission impairments in a network environment. Researchers in several countries have conducted large-scale demonstrations of quantum communications over the past year, and commercial standards activities are under way. There has been a push to conduct demonstrations with fully automated terminal equipment. New protocols allow higher speeds with greater security. A tutorial will explain fundamental concepts, and speakers will discuss detectors, coherent-state protocols, security and operation in fiber networks. In addition, three speakers will describe operation in networks.

Core Networks

IP/Ethernet and IP/wavelength division multiplexing (WDM) at 100 Gb/s and higher as well as integrated high-speed opto-electronic circuits continue to dominate the search for inexpensive and flexible alternatives to optical-electronic-optical (OEO) conversion, which is common throughout today’s core networks. IP/GMPLS leads the higher layers of networking for reconfigurability and restoration, with special provisions for highly resilient services, such as surviving multiple failures at the physical layer, as envisioned in DARPA’s CORONET program.

This is accompanied by effective means to achieve optical bypass and minimally blocking switching technologies. Further out, various forms of burst and sub-lambda circuit switching, as well as combined TDM/WDM, will enable novel architectures and bandwidth on demand. Moreover, all-optical, long-haul WDM systems, with hundreds of wavelengths, each operating at 100 Gb/s or higher, with simplified wavelength selective cross-connects, continue to hold significant promise. The research challenges of the latter systems include all-optical network monitoring, anomaly detection and automatic control of impairments. Solutions can potentially leverage decades-old methods and tools from analog systems.

All-optical core networks also have significant potential for energy conservation. However, more critical analysis is needed about the key trade-offs and effective means of comparison with today’s OEO systems and networks.

Access Networks

During the past several years, fiber-to-the-home (FTTH) has been one of the hottest topics in access. In little more than a decade, several generations of standardized time-division-multiplexed passive optical networks (TDM PONs) have been commercialized with line rates increasing from 155 Mb/s to the current generation of gigabit PONs (1.25 Gb/s for the IEEE-standardized EPON and 2.5 Gb/s for the ITU-T-standardized GPON). Soon, we can expect 10-Gb/s TDM PONs to become commercially available.

After 10-Gb/s TDM PONs, will we settle on 40-Gb/s and 100-Gb/s TDM PONs or use WDM PONs? If WDM, how and when should we upgrade the existing TDM PONs to WDM PONs? What is the most cost-effective method to implement WDM PONs operating at per-wavelength speeds higher than 10 Gb/s? Can recent core-transport innovations, such as advanced modulation formats and orthogonal frequency-division multiplexing (OFDM) technology, be applied to the next-generation access network in an inexpensive way? We will discuss these topics during OFC/NFOEC 2010.

Researchers and companies have put much effort into improving the cost-effectiveness of optical access networks by increasing the maximum reach and/or splitting ratio of WDM/TDM PONs. They have accomplished that mostly by using optical amplifiers or repeaters, but recently they have done so using coherent detection technology. The monitoring and protection of PONs remain important issues, particularly as PON evolution moves toward higher numbers of subscribers per PON. As PON speeds increase, there are continual efforts to improve the high-speed circuits for burst-mode transmission. As in most areas of communication, the energy consumption of access networks has emerged as an important research topic.

Industry researchers have also been looking to develop new technologies suitable for transferring wideband radio signals over the fiber cost-effectively, and it is becoming vital to integrate radio-over-fiber systems with optical access networks. For the latter purpose, various proposals have been put forward; these include the integration of PON and WiMAX access networks and the convergence of wired and wireless services in access and in-home networks.

Transmission

The origin of optical undersea systems dates back to the late 1980s, with the first trans-Atlantic optical system TAT-8 starting service in 1988. Two decades later, the bulk of worldwide



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international communications is carried by global undersea networks. Long-haul undersea systems have stimulated advances in technology that touch the rest of the telecommunications industry. Starting in 2005, the industry has seen resurgence in demand for major new undersea connectivity all around the world. In the first half of 2008, 70,000 km of undersea cable were contracted, and many bids include options for systems deploying 40-Gb/s channels and capacities greater than 1 Tb/s., as will be discussed by Neal Bergano

Usage of the available optical transmission spectrum in long-haul fiber-optic systems is continuously increasing.

In terrestrial systems, we are quickly approaching bandwidth limitation, so

the use of non-binary formats becomes necessary, allowing much denser spectral packing of information and thus providing higher aggregate capacity. This topic will be discussed by Alan Gnauck.

However, from reasoning based on the Shannon information theory, one can compute a capacity limit for fiber-optic communication using advanced technology. Recent experimental results are within a factor of five of this limit. The use of multilevel formats means that electronic digital processing is playing an increasingly important role in such systems by allowing effective signal recovery and the mitigation of impairment from chromatic dispersion, polarization-mode dispersion, etc. This is particularly true for coherent reception of the signal, as will be covered by Maxim Kuschnerov.

As Xiang Zhou will emphasize in his presentation, the algorithms used to recover the signals also play a key role in the resulting performance and system robustness. However, non-coherent approaches, such as sequence estimation, can also be very powerful in impairment mitigation and increasing spectral efficiency. This topic will be addressed by Nicola Alic. High-speed analog-to-digital conversion can enable 100-gigabit Ethernet, which will be discussed by Ian Dedic. This conversion is capable of real-time capture of every bit in a non-binary signal for subsequent electronic impairment mitigation, error correction, etc.

Error correction—which will be addressed by Kiyoshi Onohara—is becoming a mainstream assumption in long-haul systems. The concept of OFDM signal transmission also remains important and will be discussed by Fatima Gunning. A direct consequence of adapting multi-level signaling is that larger optical power (higher SNR) is needed, which is associated with potentially stronger impact from fiber nonlinearities. Examples, covered by Chongjin Xie, include the nonlinear polarization effects in polarization-multiplexed systems.

As optical communication systems move beyond the core and metro networks to become more and more pervasive in access networks, these high-volume applications are placing new demands on optical components.

Subsystems

Given the rapid growth of Internet traffic, we are upgrading transport systems from 40 to 100 Gb/s now and will soon approach 1 Tb/s. Wireless technologies are coming into fiber-optic communications, including not only multi-level modulation techniques such as modulation with multiple bits per symbol, phase shift keying and quadrature amplitude modulation, but also orthogonal frequency-division multiplexing (OFDM) techniques, which are being studied for long- and short-haul systems. Electrical signal processing techniques, which are very attractive for compensating the increased impairments resulting from higher line rates, require that state-of-the-art analog-to-digital-converter processing chips and algorithms be included in receivers.

In the future, various types of network elements such as colorless/directionless ROADMs and optical cross-connects will play key roles for reconfigurable lightpath provisioning in metro and core WDM networks. The industry has currently placed much emphasis on real-time signal processing techniques as well as low energy consumption of transmission subsystems and network elements for “green” IT.

These areas will be reflected in the invited talks, which include real-time processing of quadrature phase-shift keying by Chris Fludger, OFDM spectral efficiency limits by Herbert F. Haunstein, OFDM real-time processing by Qi Yang, nonlinear compensation in digital coherent receivers by Takeshi Hoshida, various issues involved in 40G and 100G deployment on 10G infrastructure by Jeran-Paul Faure, and bit-rate-flexible network elements by Kazushige Yonenaga. One workshop will be devoted to how we can groom and multiplex data for ultra-high-speed transmission (coordinated by Klaus Grobe and Erwin Pincemin) and another to 1TbE transport (Andrew Ellis and Seb Savory).

Photonic Integration

Photonic integration of optoelectronic devices is becoming increasingly important for the optical communication industry. It is considered to be the technology that will enable future capacity requirements while also reducing the cost per bit. One of the key areas for which the development of high-performance photonic integrated circuits (PIC) will be vital is that of coherent systems, as will be discussed by Chris Doerr.

Transmission system designers are looking to exploit coherent optical communications to achieve spectral efficiencies

far in excess of what is currently feasible, and it is inevitable that PICs will be required for development of practical and cost-efficient coherent systems. Another important topic is the drive to develop faster optoelectronic devices for transmitters and receivers. These high-speed devices (lasers, modulators and detectors) are the key building blocks that are necessary for enabling photonic systems operating at line rates of 100 Gb/s and above.

As optical communication systems move beyond the core and metro networks to become more and more pervasive in access networks, these high-volume applications are placing new demands on optical components. These requirements include an ultra-wide temperature range of operation; simpler, higher yield manufacturing; ease of integration; low power consumption, low power dissipation; and, above all, low cost.

Christophe Kazmierski will outline the key optoelectronic devices for optical access networks in a 10-Gb/s WDM-PON. The development of both cost-efficient and energy-efficient optical components is vital to establish genuinely high volume optical communications markets such as FTTH, automotive, enterprise systems, in-home networks, etc., and the establishment of these high volume markets will in turn be critical for sustaining photonics innovation moving forward.

Optical Fiber

In recent years, optical fiber research and development has echoed the commercial market by shifting away from traditional long-haul dispersion-managed fiber spans toward FTTx fiber and high-power fibers that often exploit non-traditional fiber designs or materials. (FTTx refers to fiber to the home, building, premises, etc.) These new technologies are poised to make a commercial impact in the next few years. For example, microstructured optical fiber technology has been harnessed for FTTx applications to create ultra-low-bend-loss FTTx fiber—which has the potential to revolutionize fiber deployment inside homes and businesses. Ming-Jun Li will review the remarkable progress made in this emergent area. And, as Michel Belanger will discuss, coherent detection allows electronic impairment mitigation, thus changing the fiber requirements.

Excellent beam quality and a geometry that is inherently favorable for thermal dissipation have enabled high-power optical fiber lasers and amplifiers to displace some traditional solid-state systems. The rapid increase in the continuous wave (CW)

and pulsed signal powers attained by high-power optical fiber lasers and amplifiers has not yet reached the ultimate fundamental power limits. This topic will be discussed by Jay W. Dawson.

As Jes Broeng will review, extremely large mode areas and high gain to maximize optical signal power have driven radical fiber designs, including actively doped solid core photonic bandgap fiber. Even telecom, which originally gave birth to high-power optical fiber technology, stands to benefit from some of the recent advances, as will be discussed by George H. BuAbbud.

Non-traditional dopants or materials systems are also playing a role in expanding the envelope of fiber performance. Bismuth-doped silica fibers will be discussed by Evgeny M. Dianov and Yasutake Ohishi will describe recent progress with tellurite fibers.

Fiber and Waveguide Devices

Advances in fiber amplifiers for optical communications systems continue to draw strong interest from the industry. High-speed burst-mode amplifiers with automatic control leveling will play an increasingly important role in high-speed optical communications. This topic will be covered in an invited talk by Yoshinari Awaji. Work continues on other aspects of fiber amplifiers, including the impact of spectral hole-burning due to channel loading and extending the wavelength regions of optical amplifiers using novel dopants. The performance of semiconductor amplifiers continues to improve. Recent advances and applications will be covered in a talk by Juerg Leuthold.

Fiber parametric amplifiers, which have demonstrated speeds of 320 Gb/s, enable tunable delay and dispersion compensation, high-speed de-multiplexing, signal regeneration and multicasting, and other applications. Andreas Wiberg will discuss some of these applications.

There is strong interest in high-power fiber lasers. Many aspects of these lasers—including narrow-linewidth operation at high powers and scalability—will be covered by Frederik Laurel. Precision control of fiber lasers is an active area of research, as it allows unprecedented accuracy in frequency measurements based on femtosecond fiber laser combs as well as narrow-linewidth CW lasers. These topics will be covered by Ingmar Hartl and Yaakov Shevy.

The many advances in fiber optic technologies also carry strong benefits for other fields. Adrian Podoleanu and Morton Ibsen will conduct a workshop on how medical sciences can benefit from technologies developed for optical



communications. Joss Bland-Hawthorn will discuss benefits to astrophotonics, and Simon Fleming will describe prospects of poled optical fibers for frequency doubling and sensing.

Optical Processing and Analog Transmission

The growth in communications capacity is pushing towards the introduction of optical processing in the network nodes. This evolution from the current electronic processing can allow larger throughput but lower complexity and cost with potentially lower power consumption and size.

Optical processing will initially inter-operate with electrical processing and

later migrate to all-optical solutions. Three invited papers will discuss the different approaches, while a tutorial by A. Poustie will introduce the key enabling devices that can allow for these technologies. The benefits of all-optical versus electronic processing are still very controversial. A particular concern will be the “green” issue—i.e., power consumption.

Another major growth area for optical technologies is in access. Optical solutions can effectively be integrated with high-capacity radio links (radio-over-fiber), which require the transmission and, in some cases, processing of optical analog signals. Other subfields, such as terahertz photonics, are also growing.

As radio access becomes ubiquitous with ever-higher capacity, radio over fiber is emerging as a flexible means to enable the deployment and operation of high capacity base stations, which allow protocol-agnostic communication in some cases. This technology will be debated in a workshop on radio over fiber for last-mile connectivity. In a tutorial, V. Urlick will explain high capacity analog links while the main technological drivers and implementation challenges of analog photonics will be covered by four invited speakers.

Conclusion

This snapshot of the state of optical communications is current as of several months before OFC/NFOEC. For updates, please visit www.ofcnfoec.org. The four decades of rapid advance that commenced shortly after the pioneering work of Charles Kao continues unabated. ▲



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