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Recent advances in optical telecommunications/Avancées récentes en télécommunications optiques

Foreword

In just a few years, a revolution has taken place in the ways we communicate with each other. This revolution includes the massive expansion of mobile voice communications, complementing fixed voice communications, of internet, of digital television, all possibly mixed in triple-play or quadruple-play offers with gradually increasing bandwidth. As an example, a typical data rate brought to the end user was 32–55 kb/s 15 years ago. Today, it can reach up to 100 Mbit/s in dedicated areas. In the core of the network, the overall data traffic has been growing by more than +50% per year for more than 20 years, as a result of the introduction of new bandwidth-hungry applications, such as high-definition video services.

In this context, the optical fibre has proved unrivalled for coping with the explosion of capacity demand. The key advantage of the optical fibre resides in its ability to guide light with very low attenuation (< 0.3 dB/km) over a wide bandwidth of about 60 THz. One key step in the history of fibre systems is the introduction of erbium-doped fibre amplifiers, in the late 1980s. They cannot operate over the entire 60 THz bandwidth, but over an already-huge 4 THz window. This window is generally filled with a set of lasers, each at a different wavelength (up to $\sim$100) and modulated at 2.5 Gb/s, at 10 Gb/s, at 40 Gb/s or soon at 100 Gb/s bit-rates. The total capacity of such fibre systems is then given by the number of lasers times the bit-rate carried by each of them. They are generally referred to as wavelength-division multiplexed (WDM) systems. Their capacity can be transmitted over several thousands of kilometres without optoelectronic regeneration. With WDM, optics has helped to drastically reduce the cost and the energy per transmitted bit of information. As a result, the use of optical fibre has been spreading across all the segments of telecommunication networks, from transoceanic submarine systems, to (inter-city) backbone systems, to (intra-city) metropolitan systems, and even to the end-user. Once installed, optical fibre networks have been, or can be, improved along four main directions: (1) to achieve longer distances without optoelectronic regeneration across nodes; (2) to be more flexible thanks to remote/automatic reconfiguration; (3) to deliver more capacity; and (4) to require less power consumption at lower cost per bit.

This special issue of Comptes rendus Physique provides an overview of the recent advances in optical fibre communications, and in the related optical technologies. It also gives directions for the future. It includes contributions of scientists from academic institutes, from component or system manufacturers, or from telecom operators.

The first article, “Optical fiber transport systems and networks: fundamentals and prospects”; by M. Joindot and S. Gosselin, relates the history and underlying physics of optical fibre transport networks. Even though it focuses on terrestrial systems, it can serve as a good introduction to the field. It discusses the challenges, and possible evolutions of networks, from an operator point of view.

The seven following contributions to this special issue provide deeper insight into each of the categories of optical systems, from the shortest to the longest. The article entitled “Access network evolution: optical fibre to the users and impact on the metropolitan and home networks”, by P. Chanclou et al., describes the introduction of optics in access networks, enabling high speed end-to-end connexions (at 100 Mb/s, 1 Gb/s...) in order to deliver fixed and mobile services. The interface with metropolitan networks, and the possibility to deliver 1 Gb/s inside the home networks via plastic optical fibre are also addressed.

The two next articles address terrestrial networks in which fibre links are longer, typically 1000–2000 km distances, usually linking major cities. Such links carry information at bit-rates equal or larger than 10 Gb/s per wavelength in frequency slots of 50 or 100 GHz. They can be highly heterogeneous because they sometimes rely on fibre sections

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installed at various periods of time, thus based on various fibre technologies. Hence, optical data travelling across these networks can be distorted by physical phenomena which vary from one fibre section to the next. Optical non-linear effects are among the most challenging of these phenomena. The article "Unified analysis of weakly-nonlinear dispersion-managed optical transmission systems from perturbative approach", by A. Bononi et al., provides a unified theoretical framework, based on a regular perturbation analysis, for the optimization of long-haul terrestrial optical transmission systems, by small-to-moderate fibre nonlinear effects. The next article, entitled "Physical design and performance estimation of heterogeneous optical transmission systems", by J.-C. Antona and S. Bigo, provides insight on system design and on the estimation of performance of an heterogeneous optical transmission system, taking into account the multiplicity of physical effects impairing propagation simultaneously, and most particularly the impact of Kerr-induced nonlinear effects.

The next contribution of this special issue "New transmission systems enabling transparent network perspectives", by A. Morea et al., discusses why it is advantageous to introduce optical transparency in nodes, as a key step toward more flexibility, and later automatic reconfiguration. Optical transparency means that only add/drop data pass through opto-electronic conversion stages, while transit data are just routed in the optical domain, i.e. free of opto-electronic regeneration. When physics-aware intelligence is embedded into transparent nodes, routing decisions can be made more efficiently, which reduces the cost and the energy consumption per transmitted bit.

Another major direction for the evolution of optical networks is the need to transport more and more bits per second, as response to the growth of data traffic. One natural solution is use lasers modulated at 40 Gb/s or at 100 Gb/s, preferably on a 50–100 GHz channel grid, that is with information spectral densities between 0.4 b/s/Hz and 2 b/s/Hz. The article "100 Gigabit-per-second ultra-high transmission bit-rate for next generation optical transport networks", from G. Veith et al., discusses the challenges and technologies behind the future introduction of 100 Gb/s bit-rate, while resorting primarily to ultra-high speed electronics. Another approach is to use coherent detection. Coherent detection was largely investigated two decades ago as a means to increase the system tolerance to noise, and the interest faded away when erbium doped optical amplifiers came into play. It has recently been rekindled as an enabling technology for the introduction of 100 Gb/s over long-haul distance, when used in conjunction with high speed digital signal processing (DSP). DSP-assisted coherent receivers can demodulate complex multi-level modulation formats and remarkably mitigate the detrimental effects that can take place during fibre propagation. They have opened a new field of research which is full of interesting prospects and may considerably change the way to design optical systems. The first generation of commercial products is already available in 2008 at 40 Gb/s, while products at 100 Gb/s are announced for 2010–2011. The article "Coherent detection associated with digital-signal processing for fibre optics communications", by G. Charlet, discusses the introduction and challenges related to such systems.

The following article is the only one of its kind of this special issue. Entitled "Submarine Networks: evolution, not a revolution", by O. Gautheron, describes the latest trends in transoceanic submarine optical systems. It particularly highlights the benefits of phase-modulation at 10 Gb/s and 40 Gb/s, as an alternative to the widespread intensity modulation.

Finally, in order to support the further evolution of high-capacity, energy-efficient optical networks, innovations in optical fibres and optoelectronic components are needed. The article "Latest advances in optical fibres", by L.A. de Montmorillon et al., reviews the most recent advances in optical fibre technology, with a special focus on single-mode, bend-insensitive fibres for fibre-to-the-home applications, and on multimode fibres for Ethernet links at bit-rates as high as 40 and 100 Gb/s. The last article, entitled "Challenges and advances of photonic integrated circuits", by H. Sillard and C. Kazmierski, stresses that the dense integration of elaborate photonic functions into Photonic Integrated Circuits may cause a similar revolution as the dense integration of transistors in electronic circuits. Very small, energy-efficient and lower-cost photonic building blocks should soon be available to system designers.

The purpose of this Special Issue was to shed light on a very active field of research on photonics, which has had tremendous impact on everyone's modern way of life. The continued growth of capacity needs suggests that there is much more to come for photonics in telecommunication.

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