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# PREFACE

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DWDM, dense wavelength division multiplexing, is a new technology that, with the help of photonic components, “bootstraps” many individually modulated optical wavelengths in a single fiber and enables bandwidth scalability to levels not possible before. A parallel to this is many differently colored threads brought together to construct a thin rope, where each thread corresponds to a wavelength. The receiving end performs the reverse function; it unravels the rope to its constituent colored threads.

In legacy systems, increasing the bandwidth of transported information by a few tens of Mbps was considered remarkable and was “big news.” In DWDM, only if the increase is by a few hundreds of Gbps does it become noticeable. In DWDM, the race for unprecedented bandwidths is on and as soon as 800 Gbps was announced, it was soon followed by another at 1,600 Gbps; currently, aggregate bandwidths at Peta-bits per second (Pbps) are discussed ( $1 \text{ Pbps} = 1,000 \text{ Tbps} = 1,000,000 \text{ Gbps}$ ). DWDM technology, systems and networks enable aggregate data rates per fiber at several Tb/s and long fiber spans (1,000 Km or more) without amplification. The significance of this becomes clear if one considers that a SONET repeater may cost thousands of dollars per signal and per 40 Km of fiber.

An information channel, when realized with a modulated optical frequency or wavelength, is termed an *optical channel*. A binary data rate modulates the optical wavelength. Most optical components in DWDM are insensitive to bit rate and all are insensitive to the content of data, with the exception of a long stream of ZEROS (or absence of light) that may affect the receiver synchronizing function. Thus, since DWDM optical components are insensitive to bit rate, in theory, each DWDM optical channel may have different information content as well as a different bit rate. The latter, along with an extremely high aggregate bandwidth, is what makes DWDM a highly attractive technology that is used in all levels and layers of future communications networks.

In communications, *multiplexing* can be accomplished at different levels. When in electronic form, many signals may be multiplexed in the time domain using time compression (or bit rate upping), such as time division multiplexing (TDM), by bit interleaving as in VTs of SONET/SDH, or by packet interleaving. In DWDM, multiplexing means many wavelengths modulated, coupled, and transmitted over the same fiber medium. The term *DWDM* has been expanded to include not only an optical multiplexing technology but also a whole suite of functions such as optical amplification, optical switching, optical equalization, optical filtering, and so on. In the acronym DWDM, D stands for *dense* (wavelengths), in CWDM, C stands for *course*, and in UDWDM, UD stands for ultradense. The term *dense* is relative and it indicates a large

number of wavelengths in a given spectral bandwidth (e.g., C-band) and thus tighter specifications (channel width, channel spacing, etc.), in contrast to few optical channels with very relaxed specifications in the same bandwidth. However, it is expected that soon, what we now call dense will be tomorrow's coarse and ultra-dense will be the true dense.

Thus, based on this technology, new optical systems are being designed and new networks are being architected. And as new systems and networks are on the drawing board and new software is developed, new issues emerge, new standards are drafted, new services emerge, and new consumer devices are offered. These new systems and networks can offer more bandwidth at less cost, and soon bandwidth will become from premium a commodity item.

This is the third book in the series on DWDM. The first book, *Introduction to DWDM Technology: Data in a Rainbow* (IEEE Press, 2000) provides a high-level introduction to DWDM technology. The second, *Fault Detection in DWDM: Towards Signal Quality and System Robustness* (IEEE Press, 2001), provides a treatise in fault mechanisms of DWDM components, systems, and networks, how they correlate, and how they are detected. This book provides a comprehensive treatment of DWDM, its technology, systems and networks, and engineering design aspects. In all, it provides an A-to-Z approach to DWDM, how it works, how it is used in system design, how optical network architecture can benefit from DWDM, and what the design issues are. Optical components are described in detail supported by useful equations and tables but avoiding complex mathematical derivations. DWDM systems and networks are supported by telecommunications fundamentals and legacy systems. New areas pertinent to DWDM (such as wavelength diversity), network and service survivability are explained. Failure modes in the DWDM optical regime are identified and correlated as they impact the quality of optical signal, quality of service, system reliability, and network and service survivability to aid in engineering more robust DWDM components, systems, and networks. Finally, open issues and future trends are identified and discussed, as well as emerging technologies applicable to DWDM communications systems and networks. A fourth book provides a treatment on *SONET/SDH and ATM: Communications Networks for the Next Millennium* (IEEE Press, 1999).

It is my hope that this book will raise many questions to DWDM technologists; will excite and stimulate many communications engineers, system designers and network architects; and will aid in the design of robust, efficient, and cost-effective systems and networks. I wish you happy and easy reading.

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