Chapter 18

Ultra-Long-Haul, Dense WDM Using Dispersion-Managed Solitons in an All-Raman System

Linn F. Mollenauer

18.1. All-Optical Transmission

In the late 1990s, the telecommunications industry began to see dense WDM as the way to provide for the seemingly explosive growth in demand for transmission capacity. The usual industry practice of using electronic regeneration at every node point (typically, once every 400 to 600 km; see Fig. 18.1), however, promised to use far too much capital equipment and office space, especially if the net transmission rates were to be at terabit levels. For example, a system carrying one terabit/s in each direction, at the practical and increasingly popular per-channel rate of 10 Gbit/s, would require no less than 200 (expensive and bulky) regenerators, or OT units per node (one for each direction and channel). In the meantime, it was already well known, principally from undersea practice, that such dense WDM could be successfully carried out, without regeneration, over transoceanic distances, at least under the special conditions of the undersea environment. Thus the idea of developing an all-optical terrestrial system (which had in fact been advanced many years ago [1–3]) began to take root and to undergo engineering development by many firms.

The principal requirements for such ultra-long-haul, all-optical systems, are that the growth of spontaneous emission noise be held to the minimum possible, that the transmission mode be chosen to yield the fewest nonlinear penalties, and that the pulse behavior be periodic. The third of these requirements stems from the needs of optical networking, where the data must be instantly readable, and where standard pulses can be introduced, at least at all node points along the path. With the additional requirement to work with existing terrestrial fiber spans of typically 80 to 100 km in length between amplifier huts, the only way to meet the first requirement is to take advantage of the greatly reduced noise figure provided by distributed gain from the Raman effect. The second requirement is best, and the third uniquely met with the use of dispersion-managed solitons (henceforth abbreviated as DMS).
18.2. Dispersion-Managed Solitons

18.2.1. Introduction

With dispersion management, the transmission line consists of segments of fiber whose individual dispersion parameters \( D_{\text{local}} \) are of alternating algebraic sign and with absolute values typically at least 3 or 4 ps/nm km (Fig. 18.2). Furthermore, this arrangement, or dispersion map, is ideally periodic (although, in practice, it need not be exactly so). For each map period, the accumulated dispersions of the two segments nearly cancel, so that the path-average dispersion parameter of the map \( \bar{D} \) is small, typically no greater than about 0.2 ps/nm km. To support solitons, \( \bar{D} \) is also positive (anomalous dispersion).

\[
\text{Pure Disper. Broadening (low intensity)} + \text{Self Phase Mod. (Solitons)}
\]

Fig. 18.2. Dispersion-managed solitons in a nutshell.