FIGURE 4A **Maximum spectral efficiency**

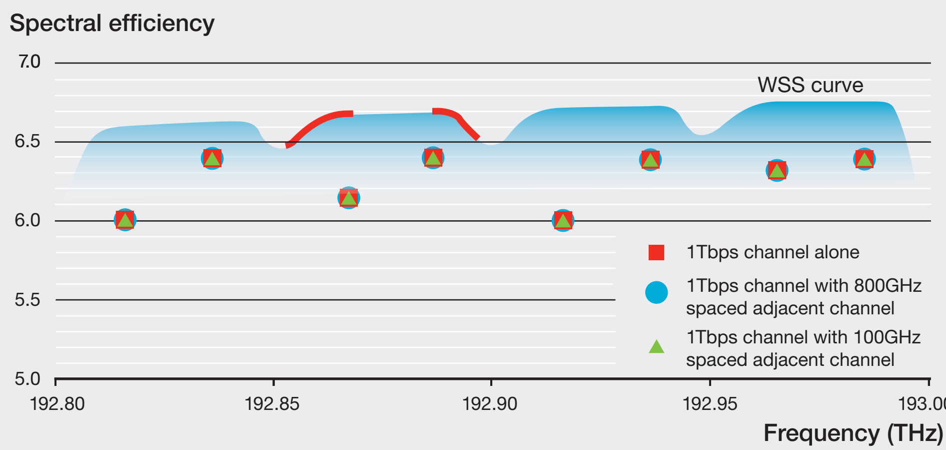
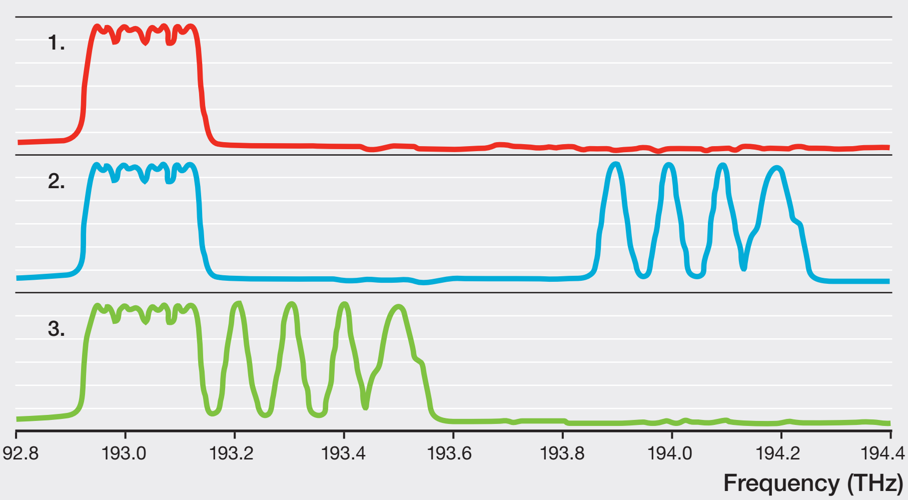


FIGURE 4B **Received spectra**



equalizer, and then by an adaptive FFE – which accounts for other linear impairments, such as polarization rotation, residual dispersion and polarization mode dispersion. The equalizer output feeds four parallel 4-state BCJR detectors[2] followed by four LDPC decoders. The BCJR and LDPC blocks iteratively exchange information, for a maximum of 20 iterations, to achieve MAP detection according to the turbo-equalization principle[3].

Field trial results

Figure 4A illustrates the measured ROADM amplitude transfer function and SE within each ROADM frequency slot for three cases:

1. 1Tbps channel alone;
2. 1Tbps channel with 800GHz; and
3. 100GHz spaced 40Gbps and 100Gbps co-propagating channels.

SE is defined as the ratio between the maximum net bitrate (not including FEC overhead) that ensures error-free operation and the ROADM bandwidth. **Figure 4B** shows the resulting SE values, obtained by optimizing the code rate individually for each carrier.

There is no appreciable difference in performance among the three cases, which implies that the interference between the 1Tbps channel and neighboring channels, with lower bitrates, is negligible. Similarly, no penalty was measured on either the 40Gbps or 100Gbps channel due to the presence of the 1Tbps channel.

To put pressure on the system, the polarization mode dispersion (PMD) was increased by means of a PMD emulator. No SE variation was detected up to 170ps of additional differential group delay, and a 5 percent drop was observed with a delay of 200ps. These are excellent results given that the maximum group delay expected in a 3,000km link is about 50ps.

To further test the stability of the solution, measurements were taken every 15 minutes during a 24-hour period, and no difference was detected in the overall performance.

By varying the carrier power (using a code rate of 5/6 for all the sub-channels), the resilience of fiber to non-linear propagation was also tested during the field trial. An optimal sub-channel power of about -1dBm was found to minimize the non-linear propagation penalty, and a maximum OSNR penalty of 1.3dB was obtained with a power range between -3dBm and 1dBm – demonstrating that TFP can cope with typical system tolerances, such as those due to gain flatness of the optical amplifiers.

Taking the optimized carrier power as -1dBm, the received OSNR with 0.1nm resolution bandwidth varies between 15dB and 1dB along the carriers – a value that is compatible with the majority of installed DWDM links.

Conclusions

The field trial demonstrates the suitability of the TFP approach to meet operator demand for high-capacity upgrade of DWDM networks. The proof points provided by the field trial show that the long-haul distances of the 1Tbps system are comparable with that of a 100Gbps system. The 1Tbps system, however, provides three times the spectral efficiency, is compatible with 50GHz ITU-T frequency grid and installed ROADMs, it can coexist with installed 40Gbps and 100Gbps channels, it provides stable operation over time, and is robust with respect to system and fiber tolerances.

Although the focus of the field was on 1Tbps transmission, the modularity of the TFP solution makes it adaptable for 400Gbps. A straightforward method of four carriers instead of eight can be used together with channel shortening and multichannel detection techniques to improve the spectral efficiency dramatically. This adaptation is important given that 400Gbps optical interfaces for metro and regional distances, based on 16QAM, are the current focus of standardization work.

But a solution for long haul, with link distances greater than 500km, has yet to be found, and TFP can play a key role in providing one: 400Gbps capabilities are being introduced in SSR and SPO product families, enabling high-speed connectivity between routers in next-generation IP over WDM and ultra-high capacity packet optical transport.

In addition, the capability of TFP to finely adjust the throughput on a per carrier basis works well with concept of SDN – where bandwidth resources need to be rerouted easily according to new service demands or dynamic changes of the traffic load – as is required by data center virtualization.

Beyond the technical result, the field trial was a good example of an agile and informal working environment, where researchers from industry and academia came together, exchanged ideas, and encouraged unconventional thinking to create an innovative solution.

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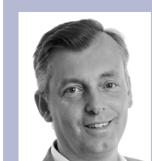

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