Beyond 100G

shaping tomorrow with you

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Introduction

Carriers face ever-increasing needs for bandwidth and capacity in their metro, regional, and long-haul optical networks due to the demands of high-speed data services, Internet video services, data centers, and higher bandwidth residential broadband connections. Until recently, most DWDM systems supported up to 88 channels with 10G data rates per channel. In order to provide additional network capacity, improved spectral efficiency, and lower cost per bit, the optical transport industry has been developing higher speed 100G technologies for the last 3–4 years. Fujitsu, along with a limited number of other vendors, introduced 100G transponders and muxponders, based on single-carrier DP-QPSK modulation and coherent detection, in 2011. Carriers have started deploying 100G units for capacity constrained routes and to support 100 GbE private line services, a trend that will continue to grow over the next few years. One of the key benefits of 100G transponders and muxponders is the ability to expand existing WDM network capacity by ten times (10x), eliminating the need for costly overbuild networks.

With 100G units entering carrier volume deployments, the optical industry is shifting focus and R&D activities to the next generation of even higher speed optical interfaces operating at 400G. Fujitsu, with an annual R&D budget of over $2 Billion, is an industry leader in high-speed photonics, including 400G. Fujitsu has been the top recipient of patents in the US Patent Office Optical Communications Category for seven years in a row [1].

Since the last 25 years have seen tremendous advances in optics and optical transport networks, it's worth looking back at the landmark achievements in the industry during this time frame.

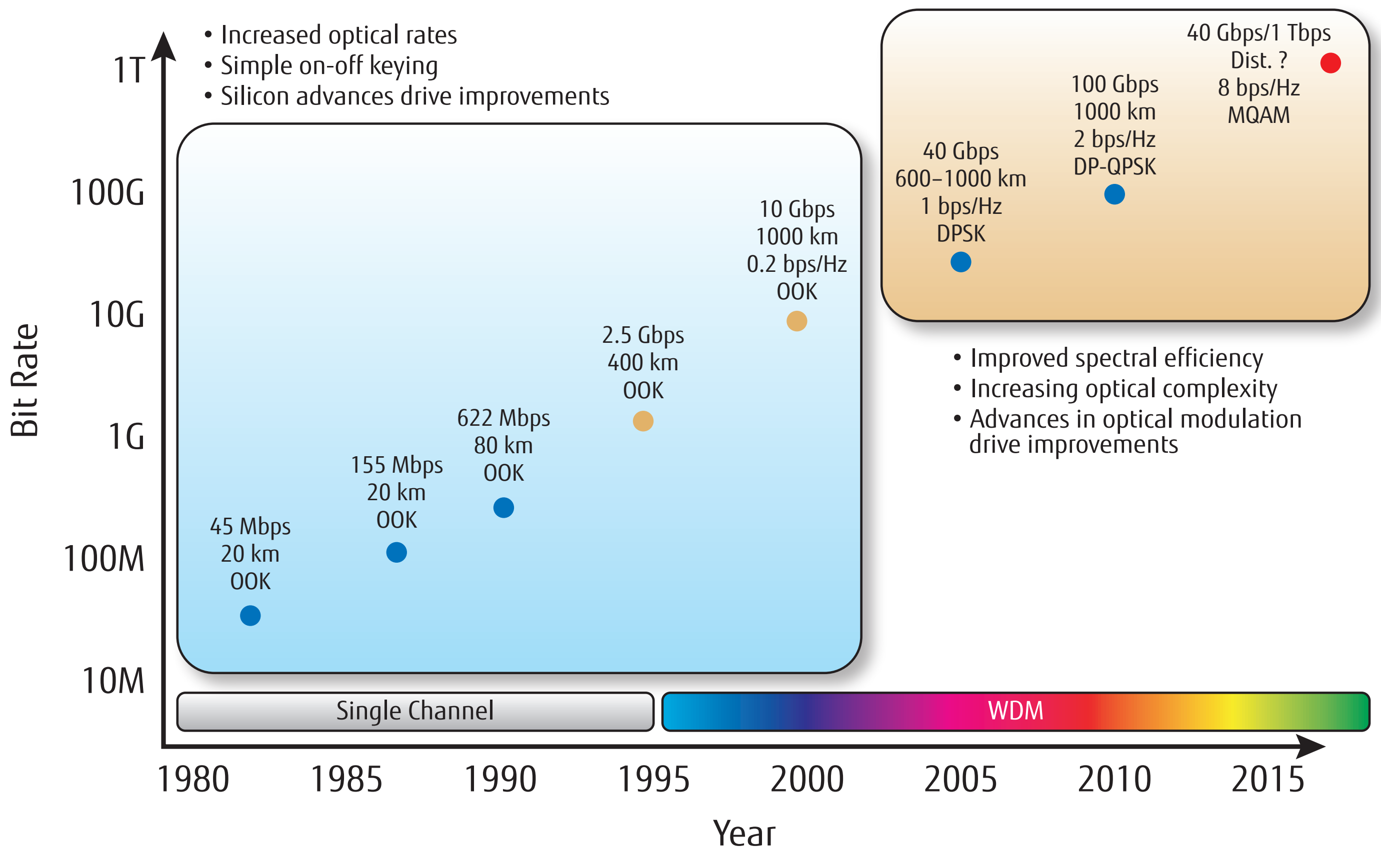

Figure 1: Advancements in optical interfaces, 1980–2015

Until the late 1990s, most optical networks were deployed as single-channel systems operating at 2.5G or 10G rates. Optical interfaces relied on simple On-Off Keying (OOK), with increasing speeds driven primarily by silicon improvements in SONET framer and laser driver chips. The introduction of WDM systems in late 1990s allowed carriers to greatly expand their network capacity by sending multiple wavelengths over the fiber simultaneously, primarily at 10G per channel rates. More recent advancements have focused on higher speeds per channel, more advanced optical modulation techniques, and improved spectral efficiency, all with the objective of increasing capacity and lowering the cost per bit. These recent advancements are driven by improvements in optical modulation, optical components, coherent detection, and DSP optical impairment compensation and FEC processing.

Increasing Network Capacity: Choices

Increasing WDM network capacity followed a well established and predictable game plan, vendors simply kept increasing the channel speeds (from 2.5G up to 10G) and increasing the overall number of channels (from 40 to 88) supported on WDM systems. With the development of 100G optical interfaces, the technical and performance issues became much, much more challenging, but were eventually resolved.

Further increases in optical network capacity come with their own set of challenges, limitations, and trade-offs, which are being reviewed and debated in the industry. Some possible options for increasing WDM network capacity are:

- Increasing optical channel rates
- Increasing the number of WDM channels
- Adding parallel systems over additional fiber pairs
- Combinations of the approaches above

Each option has its own set of trade-offs, which are being studied and evaluated. For example, increasing channel rates from 100G to 400G, also incurs additional OSNR requirements, which can impact or limit the overall optical reach of a signal, requiring additional regeneration nodes on long-haul routes. Adding parallel WDM systems over separate fiber pairs to increase capacity offers the benefit of using currently available technology and WDM platforms, but requires significant additional investment, as well as utilizing additional fiber resources.

Carriers are likely to adopt many, if not all, of these approaches in one form or another. In the near term, capacity is being increased by using additional fiber pairs, as well as migrating to 100G interfaces. Future systems will use even higher speed, 400G transponders and muxponders.

400G – Capacity versus Reach

With the introduction of 100G, the industry shifted from very simple modulation techniques (OOK) that transported a single bit of data, to much more advanced phase modulation techniques (DP-QPSK) capable of encoding and sending multiple bits at once. Along with coherent receivers, these more advanced modulation techniques enable much higher data rates and improved compensation for optical impairments such as chromatic dispersion (CD), polarization mode dispersion (PMD), and optical loss. The trade-off with these advanced modulation techniques is they require higher Optical to Signal Noise Ratios (OSNR). OSNR translates directly into the optical distances that can be achieved prior to a regeneration node. In other words, the more sophisticated and powerful the modulation, the shorter the optical reach. This trade-off between modulation technique, channel size, and OSNR requirements are at the heart of current 400G research efforts.

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Gbps	# Pol.	Gbaud	Grid (GHz)	Bits/Symbol	Modulation	OSNR (dB) min.
112	2	28	50	2	DP-QPSK	12.6
224	2	28	50	4	DP-16QAM	17.4
448	2	112	200	2	DP-QPSK	18.6
448	2	56	100	4	DP-16QAM	22.4
448	2	42	75	6	DP-64QAM	26.6
448	2	28	50	8	DP-256QAM	31.9

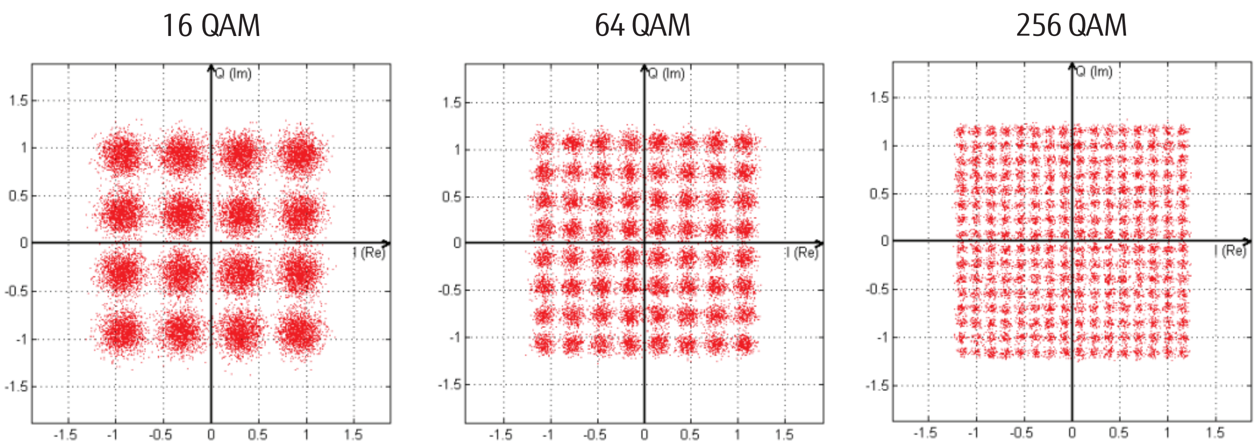

Figure 2: Capacity versus OSNR Advancement Modulation

Fujitsu is evaluating a number of advanced modulation schemes and channel sizes for use at 400G, as shown in Figure 2. In general, the higher order modulation techniques, such as 16QAM and 64QAM, encode more bits per symbol and can be squeezed into smaller channel sizes, but with the trade-off of much higher OSNR requirements.

As vendors and the optical industry evaluate these different 400G modulation, channel size, and OSNR options, it will be critical to adopt a single, standardized approach, as was achieved with 100G optical interfaces. At 100G, the industry was able to reach agreement on a single modulation technique (DP-QPSK) and channel size, working through the Optical Internetworking Forum (OIF). The industry is trying to avoid the mistakes made with 40G optics, which lacked any industry standards. As a result, an alphabet soup of five or six different 40G modulation techniques were developed by vendors, resulting in a very fractured 40G component industry, low component volumes, lack of compatible dual sources for 40G components, and few cost reductions or volume efficiencies. Fortunately, these mistakes were avoided at 100G through a common industry approach standardized within the OIF. This same approach to 400G OIF standardization will be needed to ensure a healthy, robust, component supply chain with wide choices and competitive pricing.

While Fujitsu, along with a number of vendors, have active 400G research and development efforts ongoing, the OIF has not yet started to develop formal 400G DWDM standards. However, one likely candidate for 400G modulation will be DP-16QAM utilizing two subcarriers.

Spectral Efficiency and Subcarriers

Optical fiber has enormous capacity to transport information, which is only now being utilized in a meaningful way. Optical networks evolved from single channel systems running at 2.5G to DWDM networks with 88 channels operating at 10G each. Even with this tremendous increase in capacity over the last twenty years, the spectral efficiency of WDM networks still has plenty of room for improvement. Spectral efficiency is one measure of how efficient an optical interface or modulation scheme is at using the available fiber, and is measured in the number of bits transmitted per second per Hz of optical spectrum (bits/s/Hz)

Existing 10G wavelengths use simple OOK for modulation and easily fit within the 50 GHz channel grid spacing, as shown in Figure 3. At 10G data rates, much of the 50 GHz channel is unused, resulting in relatively low spectral efficiency of only 0.2 bits/s/Hz. With 100G modulation techniques, ten times the capacity is transmitted in the same 50 GHz channel spacing, resulting in 2 bits/s/Hz spectral efficiency.

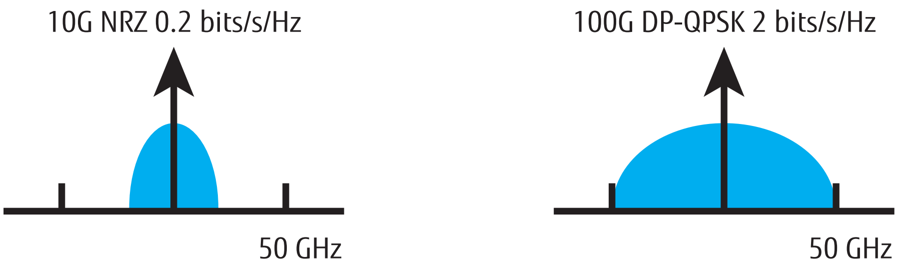

Figure 3: 10G and 100G Spectral Efficiency

At 400G rates, the industry is evaluating the optimum combination of modulation, channel size, and OSNR requirements. One likely modulation candidate under consideration for 400G is DP-16QAM with two subcarriers. Using subcarriers offers a number of key advantages, including lower data rates on each subcarrier, better fit within existing silicon technology limits, and support for standard 50 GHz WDM grid spacing or future flexible-grid spacing. Subcarriers enable very high data rates to be divided and transported over any number of closely spaced, or slightly overlapping, subcarrier channels. The lower data rates on each subcarrier enable implementations that fit within existing component-level silicon technologies, one example being the high-speed ADCs utilized in the coherent receivers. In addition, subcarriers channels can be spaced on existing 50 GHz grid channels providing compatibility with existing WDM networks, or future flexible-grid spaced WDM systems. Channel spacing and modulation have not yet been standardized at 400G, but one option gaining widespread attention is DP-16QAM modulation using two subcarriers with a total of 87.5 GHz channel spacing, as shown in Figure 4. The spectral efficiency of this approach is approximately 4.6 bits/s/Hz.

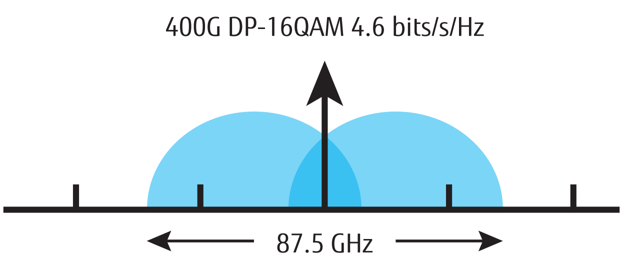

Figure 4: 400G DP-AM w/two subcarrier

FUJITSU NETWORK COMMUNICATIONS INC.
2801 Telecom Parkway, Richardson, Texas 75082-3515
Telephone: (972) 690-6000
(800) 777-FAST (U.S.)
us.fujitsu.com/telecom

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Summary

With 100G development efforts largely complete, Fujitsu is turning its R&D focus to the analysis, testing, technologies, and optical components required to implement 400G optical interfaces. Fujitsu is a leading industry innovator in high-speed photonics with generally available 100G DP-QPSK transponder and muxponder units, along with well advanced R&D efforts at 400G. Fujitsu has led the industry in US patents issued in the optical communications category for seven consecutive years. The optical industry is evaluating modulation techniques, channel size, and OSNR requirements for 400G, with the goal of a single, industry-standard approach, working through the OIF. Although still early, one leading candidate is DP-16QAM utilizing two subcarriers. Rest assured, Fujitsu is leading the industry efforts to higher speed, more spectrally efficient optical interfaces and WDM networks.

References

[1] United States Patent Office, Optical Communications, Category 398, Table of top patent awards 2011, http://www.uspto.gov/web/offices/ac/ido/oeip/taf/tecasg/398_tor.htm

Acronyms

ADC	Analog to Digital Converter
CD	Chromatic Dispersion
DP-QPSK	Dual Polarization Quadrature Phase Shift Keying
DSP	Digital Signal Processor
DWDM	Dense Wavelength Division Multiplexing
FEC	Forward Error Correction
OIF	Optical Internetworking Forum
OOK	On-Off Keying
OSNR	Optical Signal-to-Noise Ratio
PMD	Polarization Mode Dispersion
QAM	Quadrature Amplitude Modulation
R&D	Research and Development
SONET	Synchronous Optical Networking
WDM	Wavelength Division Multiplexing

FUJITSU NETWORK COMMUNICATIONS INC.
2801 Telecom Parkway, Richardson, Texas 75082-3515
Telephone: (972) 690-6000
(800) 777-FAST (U.S.)
us.fujitsu.com/telecom