Path to 400G

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Introduction

With the introduction and wide availability of 100G optical interfaces from Fujitsu and other vendors, the industry is now turning its attention to the next evolution in high speed photonics. Fujitsu is leading the industry with active research and development programs to solve the technical and component challenges posed by 400G/1 Tb speeds. Fujitsu, with an annual R&D budget of over $2 Billion, has been the top recipient of patents in the US Patent and Trademarks Office's Optical Communications Category for seven years in a row[1].

While 400G announcements tend to get all the news and media attention, substantial R&D efforts are continuing on the 100G evolution path to reduce size, power consumption and costs. For many carriers, these improvements to 100G technology will offer substantial, more immediate benefits for their networks.

Until recently, most DWDM systems supported up to 88 channels with 10G data rates per wavelength. In order to provide additional network capacity, improve spectral efficiency, and lower cost per bit, the optical transport industry introduced 100G technologies in 2012. Existing 100G optical interfaces, along with high-capacity 88-channel ROADM systems, should meet carrier capacity requirements for several years. However, the ever increasing need for speed and wider connectivity of homes, mobile smartphones, data centers, and smart machine-to-machine communications will eventually drive networks to adopt 400G optical interfaces. One of the key benefits of these higher wavelength speeds is the overall increase in network capacity, up to 24 Tb, which eliminates the need for costly overlay networks.

Benefits of Industry Standards

Within the optical industry, three standards bodies (IEEE, ITU, OIF) play a critical role in ensuring common industry technical specifications are adopted at the component, module, platform, and carrier levels. These standards ensure that the industry is focused on building and adopting common technical approaches, which creates a wide and deep supply chain at the component/module level, wide choices, increased competition and lower prices.

The optical industry has been widely praised for its efforts with 100G standards, with adoption of a common modulation format (DP-QPSK), common DWDM module (100G MSA), and common encapsulation frame (OTU4). These efforts are considered hugely successful, especially when compared with the fractured, proprietary methods implemented at 40G. When 40G optics were introduced, no industry standards were available. Vendors independently developed their own 40G implementations, which resulted in four or five different modulation formats. Because a common technique was never agreed upon, optical components suppliers were faced with very low volumes for any given method, and operators were consequently faced with higher prices and fewer supply choices. While 40G optics are widely available and deployed, from Fujitsu and other vendors, without any technical or performance issues, the lack of common 40G industry methods is viewed as a serious shortcoming.

At 400G, the industry is committed to extending the same level of cooperation, coordination, and agreement that led to successful 100G standards. However, the efforts within the three primary standards bodies to develop 400G specifications are just beginning. The process from informal discussion to ratification of formal standards typically takes 2–3 years to complete. For 400G, formal standards should be completed in 2015, which is approximately the same time most carriers are indicating they will start initial evaluation and deployment of 400G interfaces.

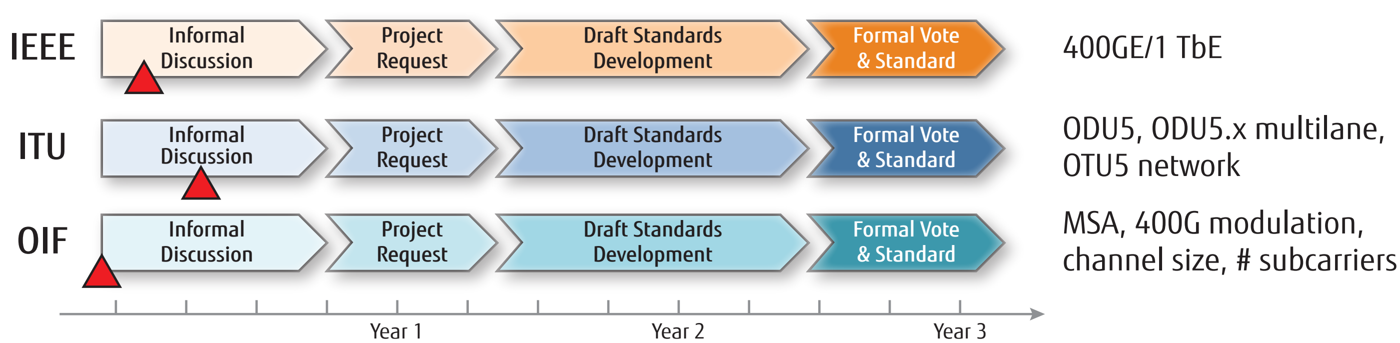

Figure 1 – Industry standards timeline

100G Evolution

While substantial research and investment in 400G is ongoing, Fujitsu is also making significant progress along a 100G evolution path that will lead to smaller device sizes, lower power consumption, and overall reduced prices. With 100G optics just beginning volume deployments, these technology enhancements will offer key benefits to carriers.

As an example, a 100G transponder is designed around a self-contained 100G transceiver, called a MSA module, for the DWDM network-side optics and a 100G CFP pluggable optical module for the client side. Both of these modules are designed to industry standards, the OIF for the 100G MSA and the CFP-MSA organization for the client-side module. The current generation of these modules are designed to accommodate the power and heat dissipation of the components inside the modules, resulting in relatively large device sizes. Fortunately, work is well under way to reduce the size and power consumption of these modules, which will enable 50% reduction in 100G transponder sizes, combined with lower power consumption.

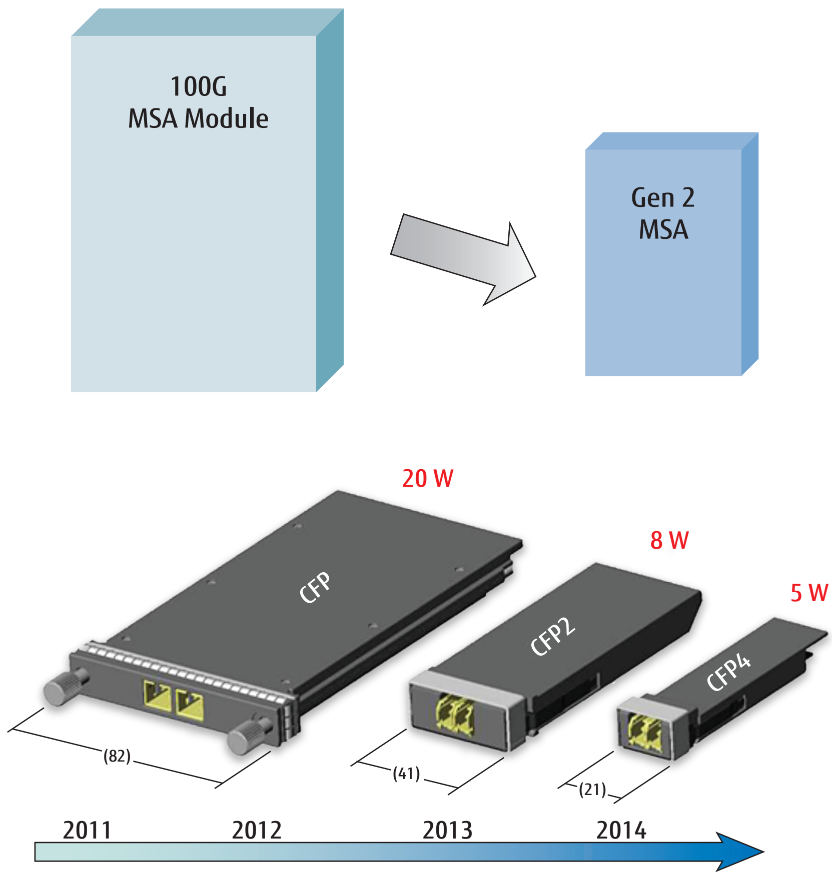

Figure 2 – 100G module evolution

Path to 400G

Increasing network capacity has followed a well-established and predictable game plan, increasing channel speeds from 2.5G to 10G to 100G, and expanding the overall number of channels supported on WDM systems from 40 to 88. 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 that they require higher Optical Signal-to-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 is at the heart of current 400G research efforts.

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

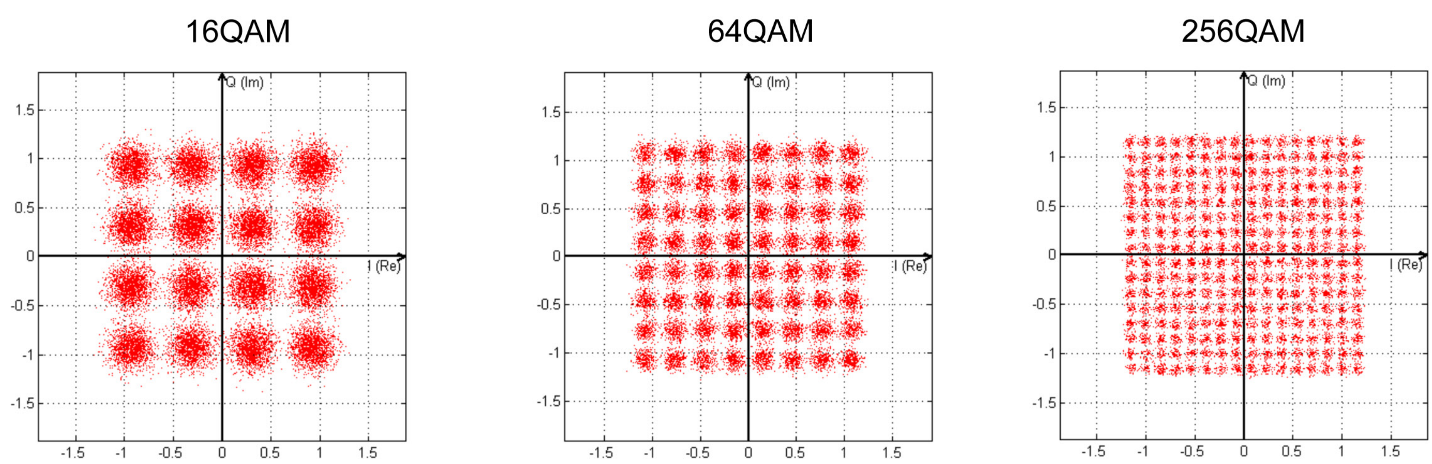

Figure 3 – Capacity vs OSNR advancement modulation

The industry is evaluating a number of advanced modulation schemes and channel sizes for use at 400G, as shown in Figure 3. At 100G, the industry was able to reach agreement on a single modulation technique (DP-QPSK) and channel size, working through the ITU and OIF standards organizations. At this time, 400G modulation has not yet been defined, but Fujitsu and the rest of the industry are focusing on two modulation options, DP-QPSK and DP-16-QAM utilizing multiple subcarrier channels (superchannels).

400G Superchannels

Optical networks have evolved from single-channel systems operating at 2.5G to DWDM networks with 88 channels, each operating at 100G. Up to this point, each of those channels has been transmitted over a single optical carrier fitting into an ITU standard 50 GHz grid pattern. Higher data rates, including 400G and eventually 1 Tb, will utilize multiple subcarrier channels to transmit data, as shown in Figure 4. These subcarrier channels are commonly referred to as "superchannels." The superchannels are provisioned, transmitted and routed across the network as a single entity, and treated as a single 400G channel.

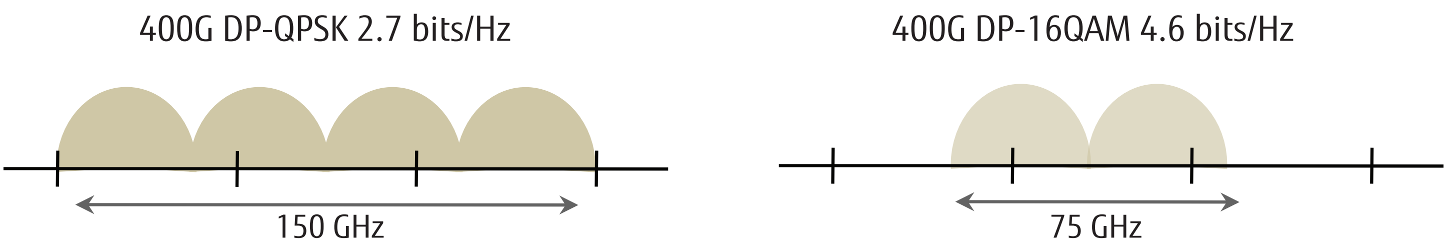

Figure 4 – 400G Modulation options and superchannels

At 400G rates, the industry is evaluating the optimum combination of modulation, channel size, and OSNR requirements. Two modulation techniques are emerging as the most likely candidates for 400G standardization: DP-QPSK, utilizing four superchannels and DP-16QAM with two superchannels. Due to the differences in OSNR requirements, each modulation type is optimized for different network applications. The four-superchannel DP-QPSK approach is better suited to long-haul networks due to its superior optical reach, while the two-superchannel DP-16QAM is ideal for metro/regional distances.

Using subcarriers offers a number of key advantages, including lower data rates on each subcarrier, better fit within existing silicon technology, and support for standard 50 GHz WDM grid spacing or future flexible grid spacing. While channel spacing has not been finalized, research has shown that each superchannel can fit within a 37.5 Hz channel, as shown in Figure 4. The spectral efficiency of this approach is up to 4.6 bits/s/Hz, a dramatic increase from the 0.2 Bits/s/Hz of existing 10G-based DWDM networks.

Fujitsu Universal Transceiver

One unique innovation for 400G is the Fujitsu Universal Transceiver, which is a single module providing software-provisioned flexible modulation, including BPSK (ultra long-haul submarine), DP-16QAM (metro/regional), and DP-QPSK (long-haul networks).

By adding high-speed Tx DSP and Digital Analog Converters (DACs) to the transmit side of the optical module, flexible modulation options can be provisioned through the DSP/DACs. A single module can be used to support 100G LH applications, or 100G/200G metro and regional applications. Combining two or more modules creates a 400G superchannel signal, and combining five modules creates a 1 Tb superchannel signal.

This added flexibility, along with a flexible-grid ROADM, enables carriers to maximize their network capacity for any application, all with a common module, an insanely great idea.

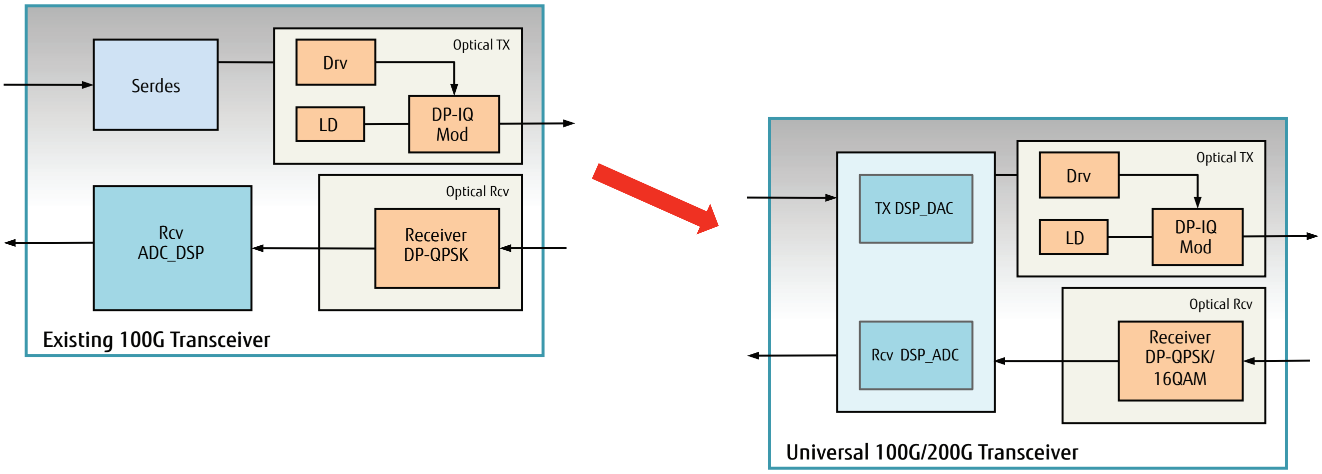

Figure 5 – Fujitsu Universal Transceiver

Reality Check

With all of the industry hype surrounding 400G, one would think carriers are facing an immediate capacity crunch, having completely filled their existing WDM networks with 100G interfaces. The reality is that most WDM networks are still primarily reliant on 10G and 40G channels, with a modest introduction of 100G units where required to relieve capacity congestion or support the occasional 100GE private line service.

The chart below indicates the number of 10G, 40G, and 100G units being sold in North America across metro, regional, and long-haul networks, based on independent industry research from Ovum[2]. For 2012, approximately 90% of all transponders and muxponders shipped were 10G, 9% were 40G, and only 1% were 100G optics.

Over time, 100G unit volumes will grow and take a larger and larger share of the overall total. While the chart and results may be a surprise, they are consistent with traditional industry rollouts of new technologies. In addition, the WDM industry recently expanded the number of channels supported on ROADM platforms from 40 channels to 88 channels. The additional channel capacity has allowed carriers to continue expanding their network capacity by adding additional 10G wavelengths. At the same time, the price of 10G ports on both ROADM platforms and routers has dropped dramatically in recent years, providing an incentive to continue adding 10G channels. Over the long term, increasing residential broadband speeds, higher smartphone data rates, increasing video streaming, and the abundance of high capacity data centers will drive networks to evolve to 100G wavelengths and then to 400G, but that transition will occur over a number of years.

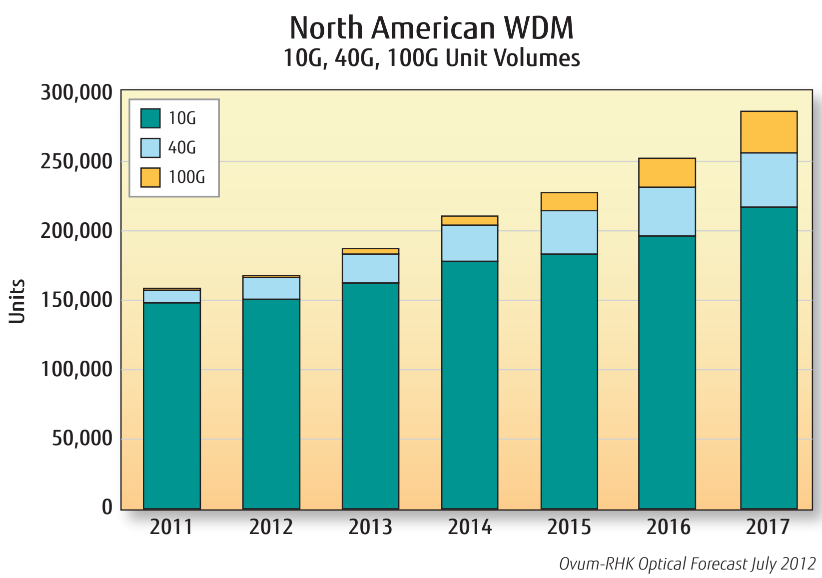

Figure 6 – 10G still dominates

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Summary

With 100G units widely available, the industry is turning its R&D focus to 400G optics. At the same time, ongoing investment and evolution of 100G technology will result in smaller size, reduced power consumption, and lower costs of 100G interfaces. Optical standards ensure a common, industry-wide approach resulting in wide supply chain choices, increased competition, and lower prices. Industry standardization efforts at 100G are widely recognized as a tremendous success. At 400G, the industry standards are in the informal discussion stage, maturing over the next 2–3 years into a formal standard. While many see the 400G standards efforts as late, they timeframe is consistent with carrier 400G deployment timeframes and reinforced by industry research from Ovum.

Fujitsu is a leading industry innovator in high-speed photonics, with the most US patents issued in the optical communications category for seven consecutive years. In addition to the 100G transponders and muxponders available since 2011, Fujitsu has well-advanced 400G research and development efforts underway. The innovative Fujitsu Universal Transceiver will allow flexible, software-provisioned modulation formats to optimize its performance to the characteristics of the application and network and will form the basis of the industry's next-generation 400G / 1Tb interfaces.

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

2) ON Forecast Report: 2012–17, Ovum, July 2012

Acronyms

ADC	Analog to Digital Converter
BPSK	Binary Phase Shift Keying
CD	Chromatic Dispersion
CFP	C-form Factor Pluggable
DAC	Digital to Analog Converter
DP-QPSK	Dual Polarization Quadrature Phase Shift Keying
DSP	Digital Signal Processor
DWDM	Dense Wavelength Division Multiplexing
FEC	Forward Error Correction
IEEE	Institute of Electrical and Electronics Engineers
ITU	International Telecommunication Union
MSA	Multi-Source Agreement
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
ROADM	Reconfigurable Optical Add Drop Multiplexer
WDM	Wavelength Division Multiplexing

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