APPLICATION NOTE

# Infinera CloudWave T Optics

*Flexible Baud Rate Setting from 28 to 69 Gbaud – Enhance the Next Generation of Coherent Technology*

Coherent technology has undergone a number of evolutions. First, it went from 40G (Generation 1) to 100G (Generation 2) and then from hard decision forward error correction (FEC) (Generation 2) to soft decision FEC (Generation 3). Then it evolved from single rate interfaces (Generation 3) to flexi-rate interfaces (Generation 4) with a baud rate still in the 30 Gbaud range but with support for additional modulation schemes enabling support for multiple line rates, typically 100G (QPSK), 150G (8QAM) and 200G (16QAM).

| | Gen 1 | Gen 2 | Gen 3 | Gen 4 | Gen 5 |
|---|---|---|---|---|---|
| Approximate Timeframe | 2008-2009 | 2010-2011 | 2012-2014 | 2015-2017 | 2017-2019 |
| Wavelength Speed | 40G | 100G | 100G | 100G/150G/200G | 100G to 600G |
| Baud Rate | 12.5 Gbaud → | ~30 Gbaud | 30 Gbaud | ~30 Gbaud → | +Higher Baud Rates |
| Forward Error Correction | Hard Decision | Hard Decision → | Soft Decision | Soft Decision | Soft Decision |
| Modulation Formats | QPSK | QPSK | QPSK → | QPSK/8QAM/16QAM → | +32QAM, 64QAM |

*Table 1: Coherent Technology Evolution*

## BENEFITS OF INFINERA CLOUDWAVE T OPTICS

- **Lower** cost per bit and increase spectral efficiency
- **Minimize** power consumption and footprint
- **Optimize** performance for any Open Line System
- **Support** new 200 GbE and 400 GbE client types

Now a fifth generation of coherent technology is emerging with support for higher baud rates and additional modulation formats. Infinera CloudWave T Optics, Infinera's fifth generation coherent optics technology, leverages DSP technology based on a 16 nm CMOS process. This offers significant advantages over fourth and fifth generation coherent based on 28 nm technology. The step change increase in transistor density of 16 nm enables the DSP to do far more while consuming far lower power and minimizing footprint. 16 nm is a key enabler for 69 Gbaud and other capabilities including linear and nonlinear compensation and enhanced FEC.

## 69 GBAUD AND 600G WAVELENGTHS

Infinera CloudWave T technology delivers an industry-leading baud rate of 69 Gbaud enabling lower costs per bit to be achieved in flexi-grid networks. With 64QAM modulation, 69 Gbaud enables single channel 600G wavelengths delivering the lowest possible cost per bit at distances of up to 300 km. 69 Gbaud also enables 200G at distances of up to 4,000 km in terrestrial networks.

## FLEXIBLE BAUD RATE SETTING

A key differentiator for Infinera CloudWave T is its ability to support a wide range of different baud rates between 28 Gbaud and 69 Gbaud. The lower baud rates are needed in fixed grid ROADM networks for maximum possible unregenerated reach (34~35 Gbaud) and for interoperability with third parties (28 Gbaud with 7% staircase FEC). Baud rates up to 46 Gbaud also play a role in point-to-point 50 GHz fixed grid networks by lowering the cost per bit and increasing spectral efficiency including support for single channel 400G.

In the majority of flexi-grid cases, 69 Gbaud will give the lowest cost per bit and the best spectral efficiency. However, there will be boundary cases where the ability to select intermediate baud rates will provide options for the best spectral efficiency or the best trade-off between cost per bit and spectral efficiency. Examples of potentially useful baud rates that align to 50G capacity increments based on standard modulation are shown in Table 2.

| | QPSK | 8QAM | 16QAM | 32QAM | 64QAM |
|---|---|---|---|---|---|
| 100G | 34.5 Gbaud | | | | |
| 150G | 51.75 Gbaud | 34.5 Gbaud | | | |
| 200G | 69 Gbaud | 46 Gbaud | 34.5 Gbaud | | |
| 250G | | 57.5 Gbaud | 43.125 Gbaud | 34.5 Gbaud | |
| 300G | | 69 Gbaud | 51.75 Gbaud | 41.4 Gbaud | 34.5 Gbaud |
| 350G | | | 60.375 Gbaud | 48.3 Gbaud | 40.25 Gbaud |
| 400G | | | 69 Gbaud | 55.2 Gbaud | 46 Gbaud |
| 450G | | | | 62.1 Gbaud | 51.75 Gbaud |
| 500G | | | | 69 Gbaud | 57.5 Gbaud |
| 550G | | | | | 63.25 Gbaud |
| 600G | | | | | 69 Gbaud |

*Table 2: Intermediate Baud Rate Examples*

## ADDITIONAL MODULATION FORMATS

The option of additional higher modulation formats also has a role to play in terms of increasing spectral efficiency and lowering the cost per bit at shorter distances. Infinera CloudWave T adds 32QAM and 64QAM to the QPSK, 8QAM and 16QAM already available with the previous generation of Infinera CloudWave Optics. Furthermore, Infinera CloudWave T is able to support time domain hybrid modulation. This hybrid modulation mixes symbols with different modulation on the same wavelength. For example, hybrid 8QAM/QPSK could alternate 8QAM symbols and QPSK symbols delivering a modulation with a capacity and spectral efficiency that is the average of the two individual modulations. As the input signal quality to the FEC block is the average of the lower and higher order modulation, the reach will get near to the average of the two individual modulations. In addition, the ratio of symbols can change (for example, 2xQPSK symbols then 1x8QAM) to provide even more granularity.

## ENHANCED FORWARD ERROR CORRECTION

FEC provides an additional lever to decrease the cost per bit and increase the spectral efficiency of the network. By reducing OSNR requirements, FEC enables better reach or more capacity with a higher baud rate and/or higher modulation. Infinera CloudWave T supports a 27% soft decision FEC, which together with other enhancements, reduces the OSNR requirement by up to 1 dB, relative to the previous generation of Infinera CloudWave Optics with 25% soft decision FEC. In addition, Infinera CloudWave T supports 15% FEC and a 7% staircase FEC for interoperability with third-party interfaces in metro applications.

## INFINERA CLOUDWAVE T BENEFITS

### Cost Per Bit and Spectral Efficiency

69 Gbaud, baud rate flexibility, additional higher order modulation schemes, hybrid modulation and enhanced FEC all have the potential to lower cost per bit and/or increase spectral efficiency. However, realizing this potential requires optimally setting all the parameters including baud rate range, modulation, FEC, power levels, channel frequency and super-channel schemes. This capability is provided by Infinera Aware Technology. Infinera Aware Technology comprises two key elements, the Optical Performance Engine (OPE) and the Margin Processing Engine (MPE). The MPE is able to measure the real-time residual margin of each channel while the OPE is able to generate the valid parameter options for each channel enabling the best options to be automatically selected by the NMS, SDN or ASON/GMPLS control plane. For more details on Infinera Aware Technology, refer to the Infinera white paper *Evolving the Awareness of Optical Networks*.

### Minimize Power Consumption and Footprint

The higher density and lower power consumption of 16 nm technology enables Infinera CloudWave T to deliver a 3x improvement in interface capacity with the same power consumption as the previous generation of Infinera CloudWave Optics. Infinera CloudWave T reduces the W per Gb/s by two thirds from 0.45 W per Gb/s to 0. 15 W per Gb/s, which is significantly lower than the figures between 0.4 W per Gb/s and 0.74 W per Gb/s currently claimed for fifth generation coherent by other equipment vendors.

### Optimize Performance for Any Open Line System

Open line systems (OLSs) are a key trend in the optical networking industry. However, OLSs can have a wide variety of capabilities such as the DWDM grid, amplifier performance, power monitoring and link control. Baud rate and modulation flexibility enables the performance of any OLS to be maximized regardless of its capabilities. Furthermore, 28 Gbaud, QPSK and 7% staircase FEC provide an option for interoperability with third-party and pre-fifth generation coherent interfaces over shorter distances.

### Support for New Client Types

The ability to support 100G to 600G per wavelength in 50G increments provides an ideal solution for supporting 200 GbE and 400 GbE clients. FlexE and FlexO enable client bandwidth to adjust to the maximum wavelength capacity enabled by the combination of Infinera CloudWave T and Infinera Aware Technology.

## KEY INFINERA CLOUDWAVE T OPTICS FEATURES

**Dual lambda DSP with two flexi-rate interfaces**
- 100-600G/lambda
- QPSK, 8QAM, 16QAM, 32QAM, 64QAM and hybrid modulation schemes
- Each lambda can have a different rate in 50G granularity
- Granular baud rate from 28 - 69 Gbaud

**Programmable FEC**
- 27% FEC with 12.0 dB net coding gain
- 7% and 15% FEC for interworking and spectral efficiency

**Non-differential encoding**

**Chromatic Dispersion tolerance of >14,000 km (>300 ns/nm)**

**PMD: Up to 50 ps mean DGD**

**Extreme fault tolerance to lightning strikes in aerial fibers**
- SOP rotation tolerance: >3M Rad/s

**Performance Monitoring**
- CD, PMD, PDL, Q-factor, pre-FEC BER
- OUT-Level PM, Delay Measurement and TCM
- OSNR and Residual Margin with Coriant Aware Technology
- PRBS test and loopback

**Spectral shaping including WSS filtering mitigation**

**Non-linear compensation**

**50 ms line protection including Coherent Colorless Add/Drop**

**AES256 Encryption**

**Low power: 0.15 W per Gb/s**



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