High latency of optical modules



Overview

Latency and Latency variation are very important in applications requiring accurate timing (e.g. 5G). A solution for accurately measuring the Latency of PAM4 optical modules is required.

Key Takeaways

High latency in optical modules is primarily caused by propagation delays, processing delays in digital signal processors (DSPs), and equipment-related factors, but it can be measured and mitigated through compensation and careful design.

Causes of High Latency

Propagation Delay: The fundamental contributor to latency is the time it takes for light to travel through optical fiber. Light moves slower in fiber (~200,000 km/s) than in vacuum, adding roughly 5 microseconds per kilometer one-way. Longer fiber paths naturally increase latency.

Processing Delay: Modern optical modules, especially those using high bit rates (50 Gb/s and above) and advanced modulation formats like PAM-4 or coherent optics, rely on complex DSPs. These processors introduce additional delays in both transmission (Tx) and reception (Rx), which can vary significantly depending on the module design. Equipment Delay: Intermediate network elements such as amplifiers, ROADMs, and transponders add small but cumulative delays, typically 0.

1–0. 5 ms per node, which can become significant over long paths. Queuing and Transmission Delays: While optical networks have high bandwidth, congestion or suboptimal network design can cause queuing delays at nodes, further increasing overall latency.

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Measurement and Compensation

Latency Measurement: Latency in optical modules is measured from the transmitter input to the receiver output. Design Validation Testing (DVT) involves measuring Tx and Rx propagation delays under various conditions, including link restarts and temperature variations.

EEPRO

M Compensation: Many optical modules store latency compensation values in their EEPROM, which can be applied at the node level to correct for Tx and Rx delays. This is particularly important for applications requiring precise timing, such as 5G networks or financial trading systems.

Class-

Based Standards: ITU-T G. 8273. 2 defines latency budgets for different classes of pluggables.

For example, Class C. 2 pluggables allocate 2% of the clock tolerance error (cTE) budget for latency, while simpler Class A. 20 pluggables may allocate up to 20%.

Mitigation Strategies

Optimized Module Design: Using simpler analog signal chains or minimizing DSP complexity can reduce processing delays. Network Planning: Reducing the number of intermediate nodes and optimizing fiber paths can lower cumulative latency. Calibration and Compensation: Applying measured compensation values from module EEPROMs ensures that Tx and Rx delays are corrected, enabling deterministic latency for time-sensitive applications.

High-

Performance Transceivers: Selecting transceivers with low inherent latency (e.g., 3 ns for 10G modules) can significantly improve overall network performance.

Impact

High latency in optical modules can affect real-time applications such as 5G transport, cloud services, and high-frequency trading, where microseconds matter. Understanding the sources and applying compensation techniques is critical to maintaining network performance and synchronization.

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