Challenges of Engineering the Synchronization Plane over Optical Networks to Deliver a High Accuracy Synchronization Service

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IEEE 1588 Precision Time Protocol PTP Performance

- **Packet Delay Variation (PDV)**
  - Buffers of protocol stack
  - Queueing delay in switches/routers
- **Asymmetry**
  - Half the difference between the propagation times in two opposite directions
  - Deterministic or stochastic

Time Transfer in Local Area Networks (LANs)

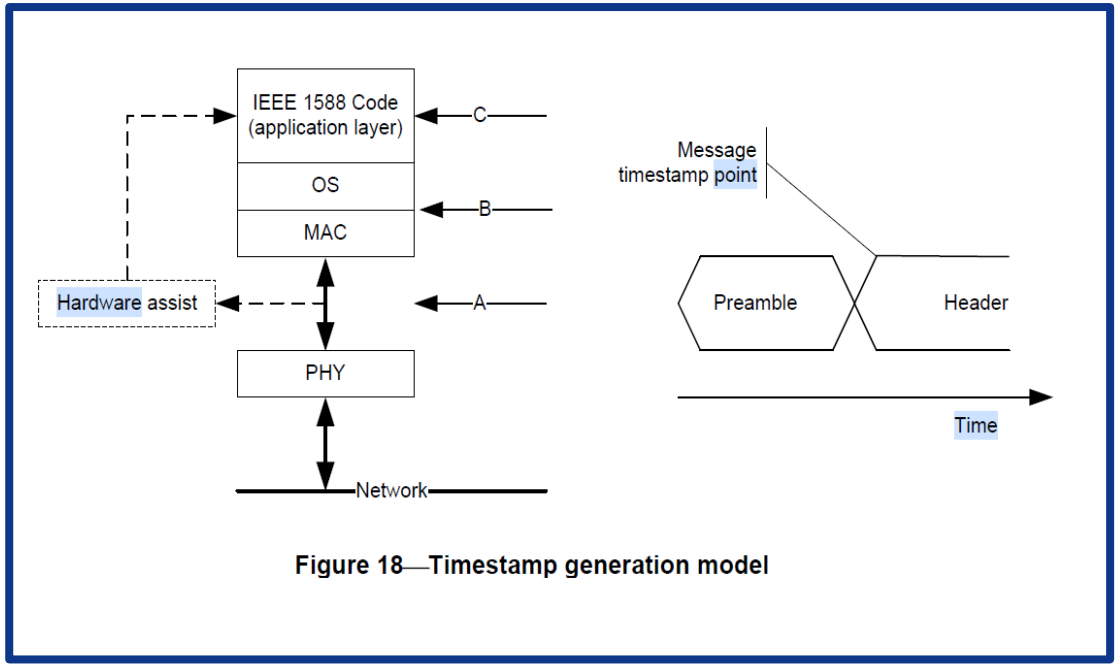
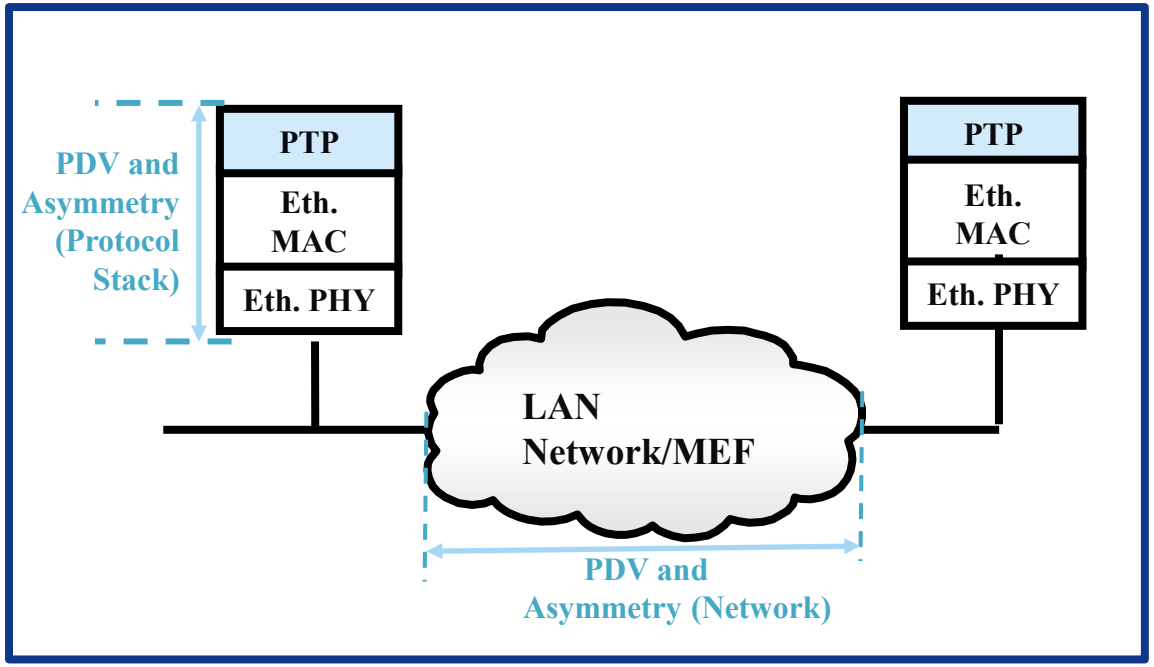


Figure 18—Timestamp generation model

IEEE-1588 2019



- Timestamp precision can be enhanced further by measuring phase offset between local PTP and SyncE
  - Digital Dual Mixer Time Difference DDMTD phase detector or carrier phase measurement

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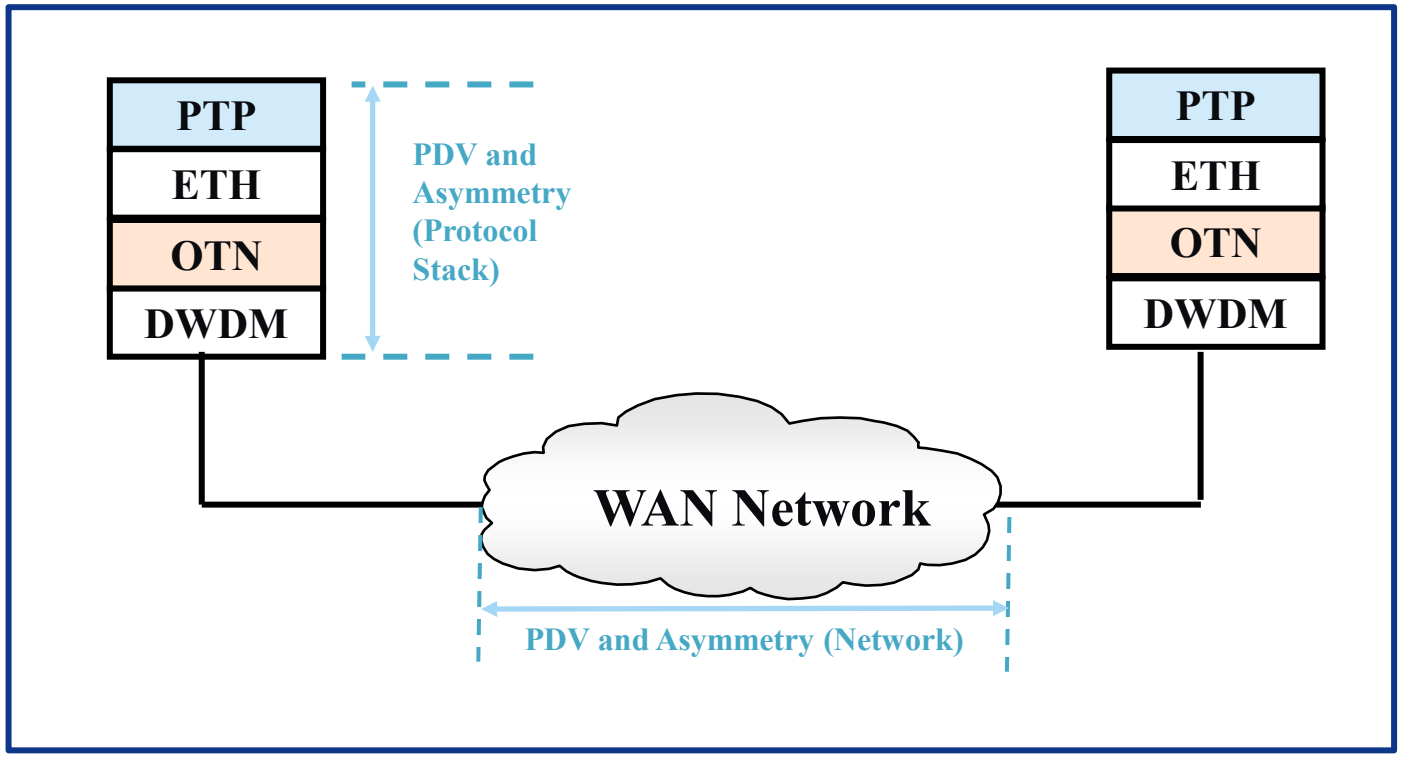
Time Transfer in Optical Networks

- **OTN Mapping**
  - Deep FIFO buffers
  - Delays vary randomly on reboot
  - Different delays on each reboot
  - Constant Time Error: up to 900 ns
- **Optical Devices on path**
  - Asymmetry



Type of Optical Networks

- Access Networks
  - Up to 80 kms
- Metro and Regional Networks
  - 80-1000 kms
- Long-Haul Networks
  - 1000-2500 kms
- Ultra-Long Haul and Submarine Networks
  - Beyond 2500 kms

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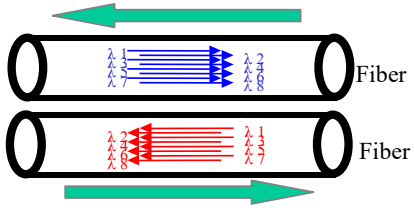
Optical Networking

Time Transfer Asymmetry – Path Lengths

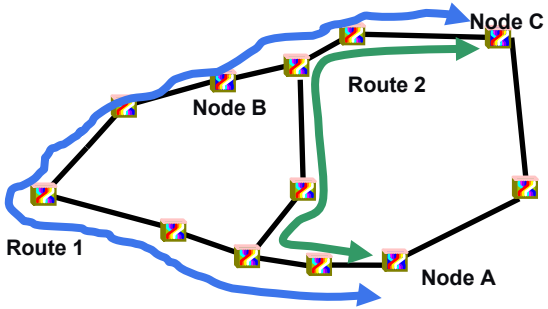
- Two strands of single-mode fiber (most common)
  - Two unidirectional paths (simplex transmission)

- Fiber lengths (different paths, different strands, etc)
  - 7m of SMF fiber corresponds to a 35 ns delay (5 ns/m)
  - Two strands randomly picked from same cable
    - Length mismatch in the range of 3% to 5%
    - 5% length mismatch on 100 kms is 250 ns asymmetry

- Protection/restoration switching
  - New path is selected



Uni-directional



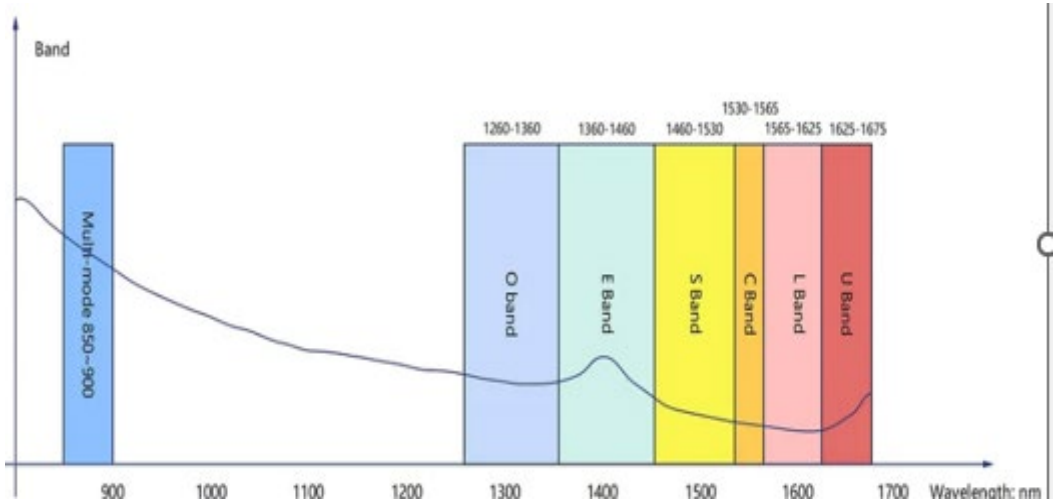
- Difference of wavelength propagation times
  - Different wavelengths travel at different speeds within an optical fiber
  - Typically, 1310 nm and 1550 nm wavelength diplex causes 33 ns to 49 ns time difference (in the function of fiber characteristic, ITU-T G.652) over 20 kms

Optical Networking

Linear Impairments

- Attenuation
  - Loss of Signal Strength
- Chromatic Dispersion (CD)
  - Distortion of pulses
- Polarization Mode Dispersion (PMD)
  - Another type of dispersion caused by asymmetrical fiber core
- Optical Signal to Noise Ratio (OSNR)
  - Noise in transmission

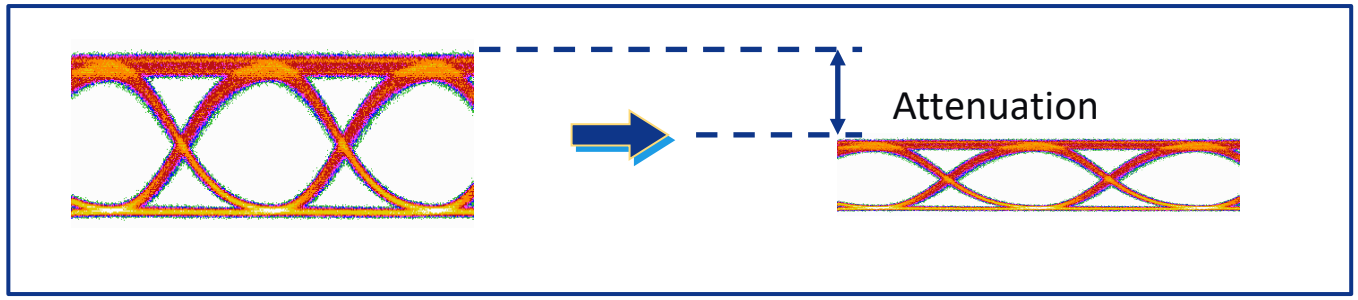
Loss(dB)/km vs. Wavelength

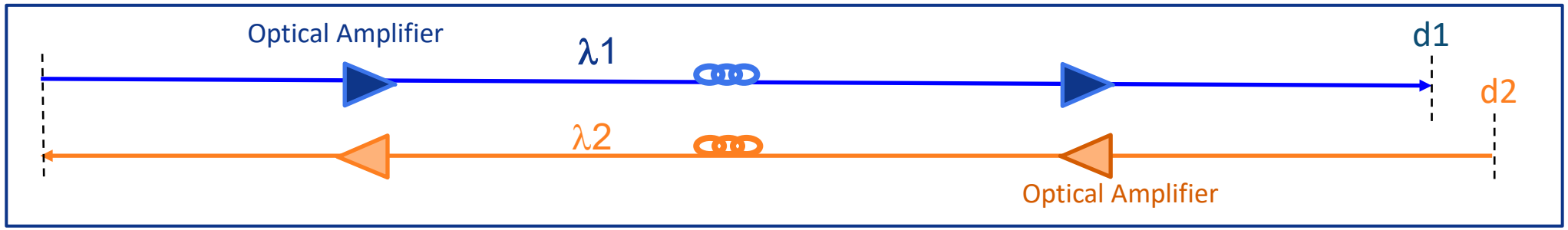


Optical Networking Devices

Signal Attenuation

- Signal may not be detected by remote optical receiver

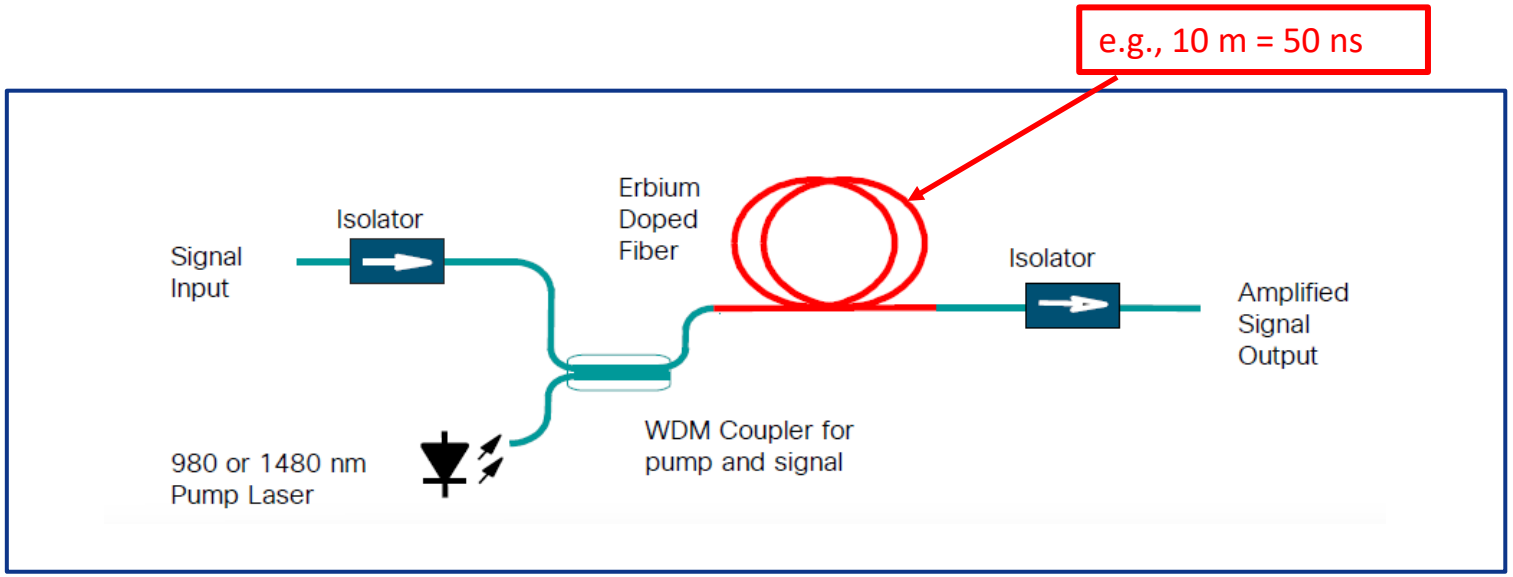




Optical Networking Devices

Time Transfer Asymmetry - Optical Amplifiers

- **Erbium Dopped Fiber Amplifier (EDFA)**
  - EDFA amplifies signal through stimulated emission using 980 nm and 1480 nm pump lasers
  - Optical Amplifier typically performs a unidirectional operation



Addition of hundreds of ns of asymmetry in one direction

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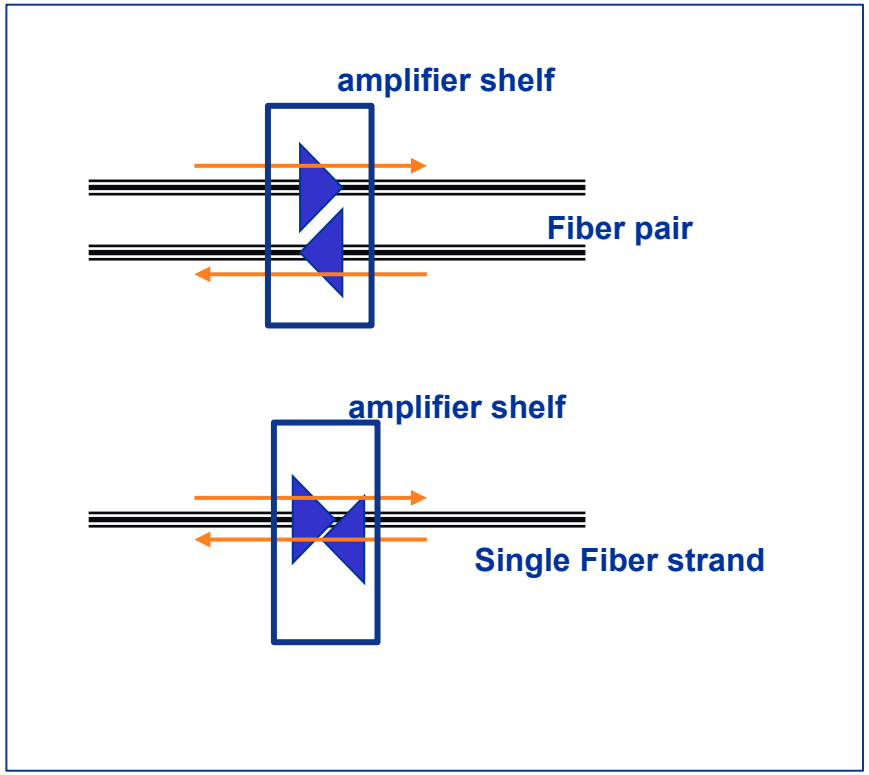
Optical Networking Devices

Time Transfer Asymmetry - Optical Amplifier

- **Uni-directional amplification**
  - More economical
  - Simple to build
  - More bandwidth

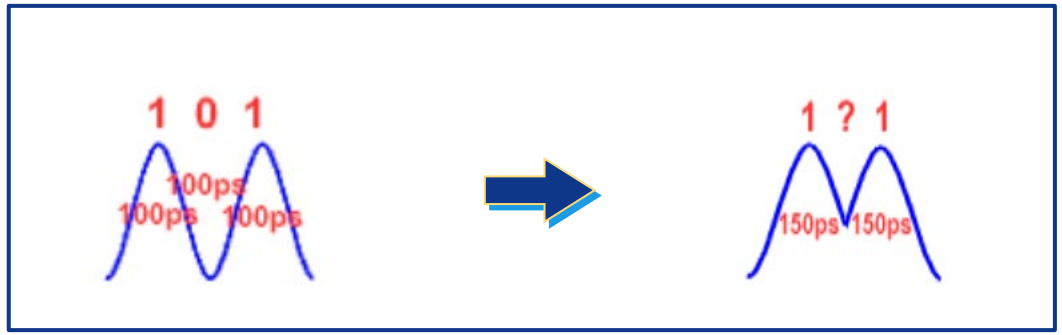
- **Bi-directional amplification**
  - Less economical
  - More complex to build
  - Less bandwidth

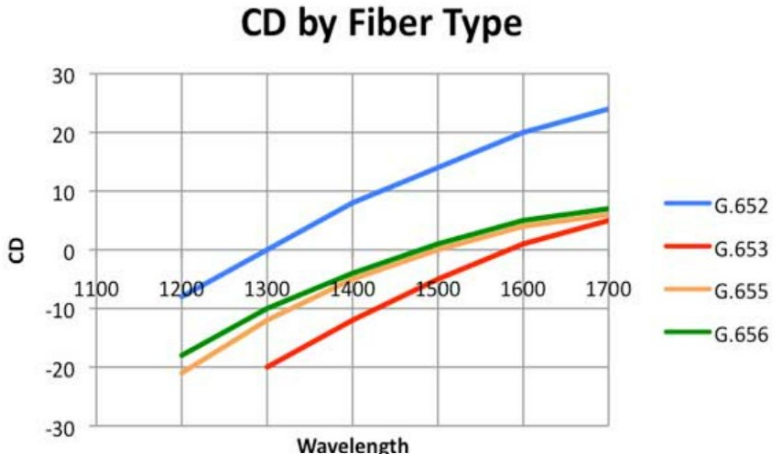


Optical Networking

Chromatic Dispersion - CD

- Pulse broadening causing intersymbol interference
- Pulses overlap due to different signals travel with different speeds
  - Longer wavelengths travel faster
- Chromatic Dispersion of a fiber (ps/(nm*km))
  - Differential delay, or time spreading (in ps) for a source with a spectral width of 1 nm traveling over 1 km of the fiber





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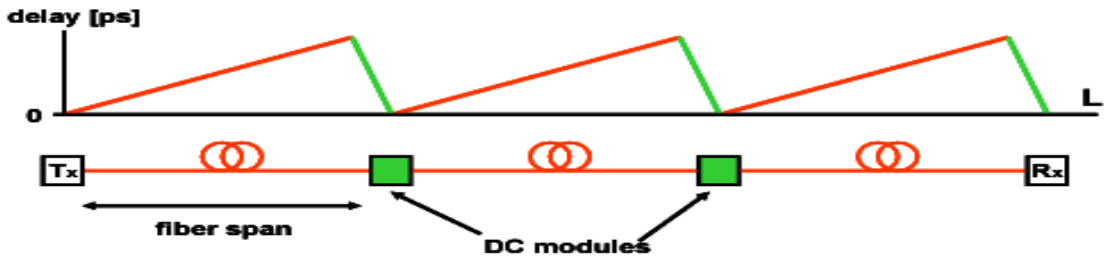
Optical Networking Devices

Time Transfer Asymmetry: Dispersion Compensating Unit – DCU

- Chromatic Dispersion is typically compensated by using negative dispersion using Dispersion Compensating Unit
- DCU is fiber with chromatic dispersion of opposite sign/slope to bring dispersion close to zero
  - Reverses operation of dispersive fiber
- DCU performs a unidirectional operation
- CD can also be compensated electronically through modulation schemes at higher speeds
  - Coherent Detection at 100 Gbps and beyond – Asymmetry of DSPs



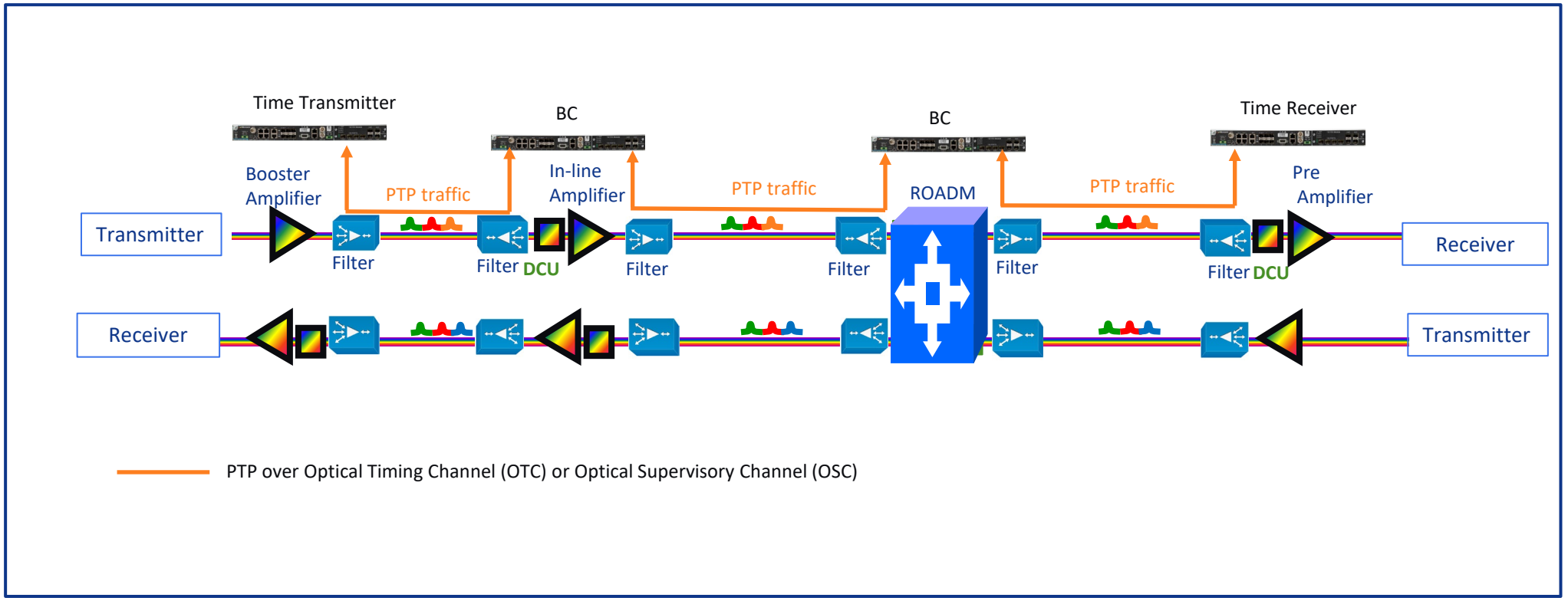
DC module: e.g., 40 kms = 2 usec, SMF fiber

Ciena

Addition of several hundreds of ns of asymmetry in one direction

Optical Networking

PTP Traffic Engineering



Summary

- **Asymmetry is a big issue for Time Transfer in optical networking**
  - Go around optical devices
- **Optical Timing Channel OTC or Optical Supervisory Channel OSC**
- **One fiber for transmit and receive**
  - Bi-directional BiDi SFP (e.g., 1310 nm/1490 nm)
- **Calculate difference between wavelengths propagation times**
- **Full on-path (Boundary Clock) Architecture**

Thank You