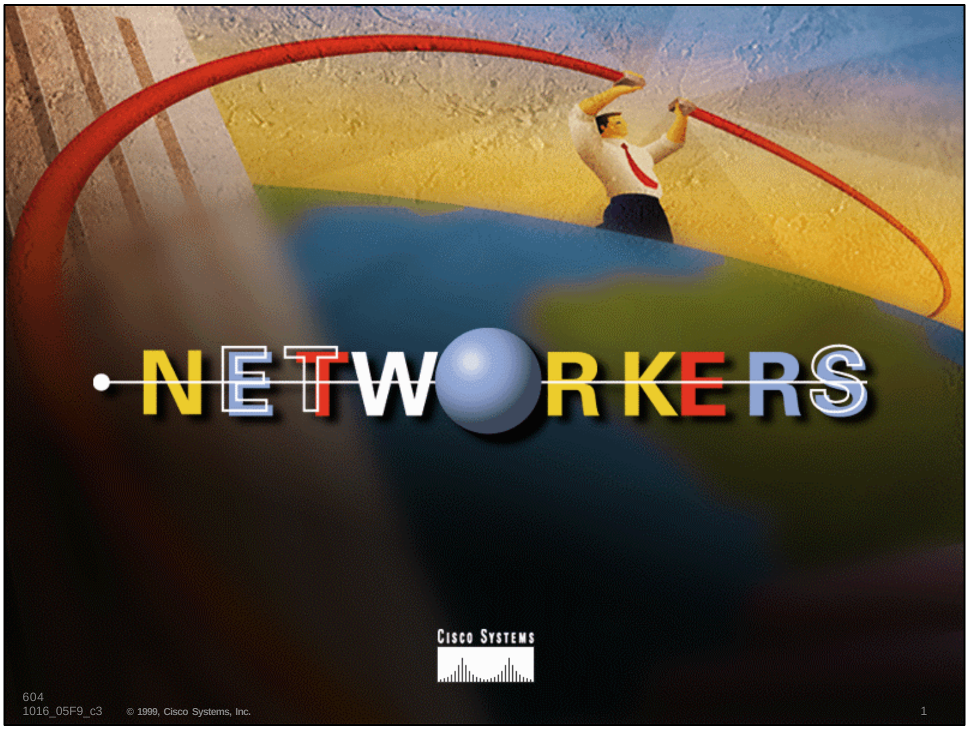
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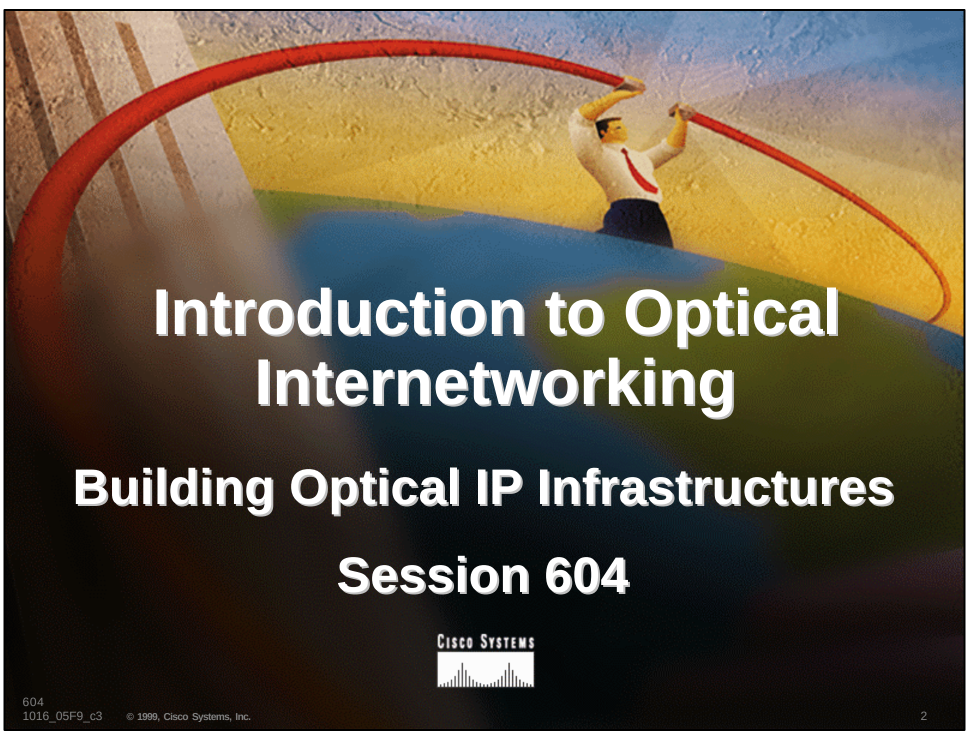
Introduction to Optical Internetworking
Building Optical IP Infrastructures
Session 604
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2

Agenda

- Introduction
- Introduction to Optical Technologies
  - Fiber Optics
  - DWDM
  - SONET/SDH
- Optical Internetworking
- Summary

Data Traffic Exceeding Voice Traffic on Carrier Networks

> "Today, of course, data traffic is becoming an ever bigger part of the mix. In fact, this year marks the crossover point: for the first time, our networks will carry more data than voice…we will soon be routing voice over data networks."

Richard C. Notebaert
CEO, Ameritech
The New York Time, May 17, 1998

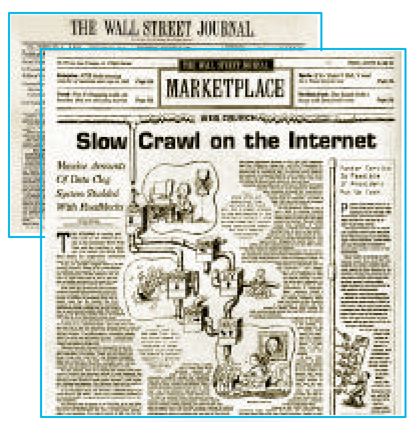
Service Providers Need to Plan for Future Services

“From 2000 on, 80% of service provider profits will be derived from IP-based services.”

CIMI Corp.

Current Network Not Optimized for Packet-Based Services

- **Most service provider infrastructures are based on circuit switched technologies**
- **These infrastructures are optimized for n x DS0 for implementing voice, leased-line services**

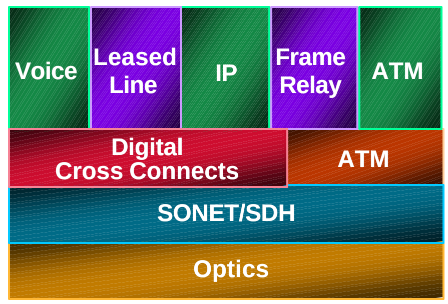

THE WALL STREET JOURNAL

MARKETPLACE

Slow Crawl on the Internet

Circuit Switched Infrastructures

- Circuit switched infrastructures were used first to offer voice and leased-line services and early IP services
- ATM was used as a more efficient circuit switched infrastructure and for Frame Relay and IP transport



Agenda

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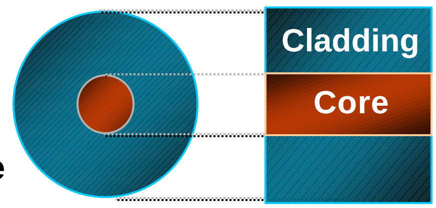
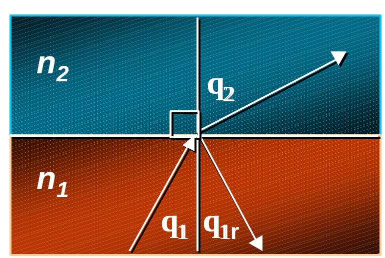
Light Propagation in Optical Fiber

- **Optical fiber consists of:**
  - **Cylindrical core**
  - **Surrounded by a cladding**
- **Both made of silica (SiO_2) that has a refractive index of 1.45**
- **Refractive Index (n) is the ratio of the speed of light in vacuum to the speed of light in that material**
- **n (core) > n (cladding)**



Geometrical Optics Approach

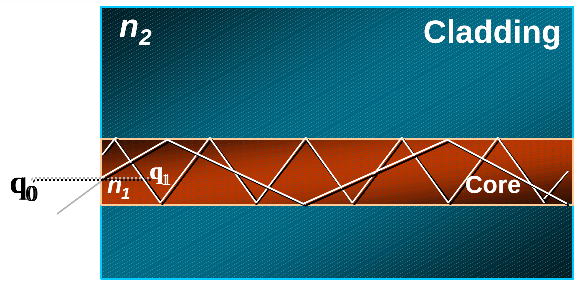
- **Light is a number of 'rays' propagating in straight lines in a medium and getting reflected/refracted at the interface**
  - **q_1 = Angle of incidence**
  - **q_{1r} = Reflected ray**
  - **q = Angle of refraction**
- **As q_1 increases, q_2 increases; when q_1 is $Sin^{-1}(n_2/n_1)$, q_2 = 90 degrees you get total internal reflection**



$q_1 = q_{1r}$

$n_1 Sin\ q_1 = n_2 Sin\ q_2$

Total Internal Reflection



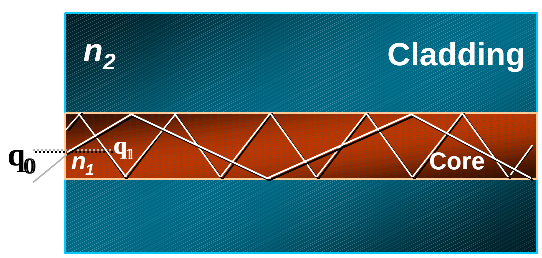
- Light propagates in optical fiber due to a series of total internal reflections that occur at the core-cladding interface
- The smallest angel for which total internal reflection occurs is called the critical angle Sin-1(n2/n1)

Different Types of Fiber

- **Multimode Fiber**

  Core diameter is about 50μm (Step Index) or 62.5μm(Graded)

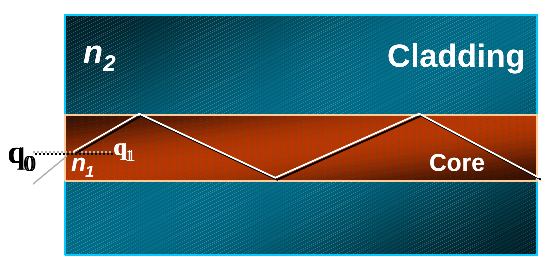
  Light propagates in the form of multiple modes, each taking a slightly different path



- **Single-mode Fiber**

  Core radius is smaller (9μm) cladding around 250 μm)

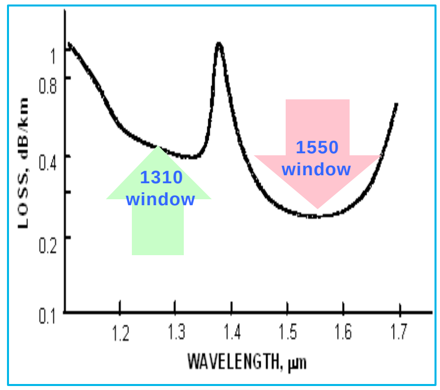
  Only one mode in which light can propagate



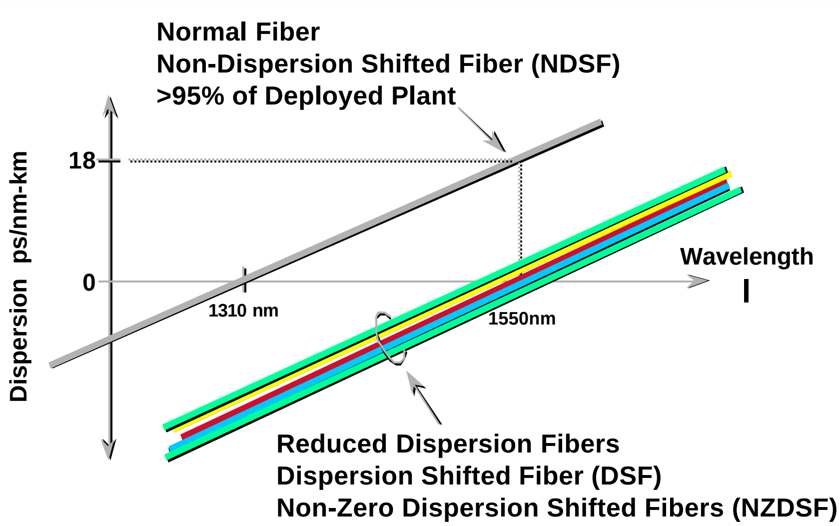
Optical Attenuation

- **Specified in loss (dB) per kilometer**
- **Scattering caused by collisions of photons with the molecular structure of the fiber**
- **DWDM considerations**

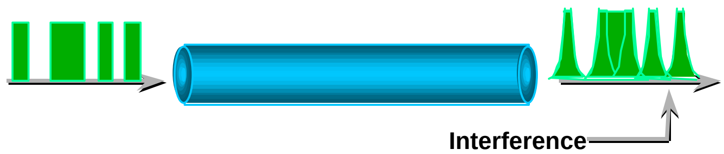
  For every doubling of channel count, the per channel optical power decreases by 3 dBm



Fiber Dispersion



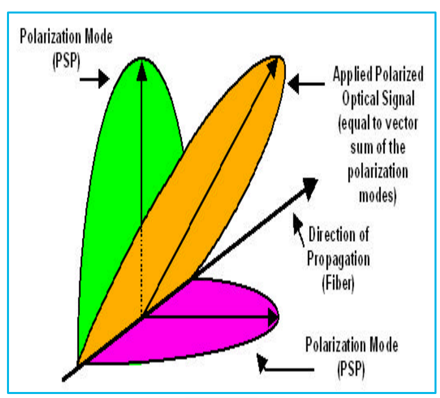
Dispersion



- Dispersion causes the pulse to spread as it travels along the fiber
- Chromatic dispersion is important for singlemode fiber
  - Depends on fiber type and laser used
  - Degradation scales as (data-rate)2
- Modal dispersion limits use of multimode fiber to short distances

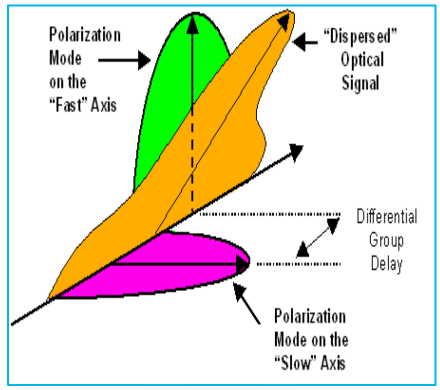
Polarization Mode Dispersion

- Imperfections in the crystalline structure of the fiber
- Manufacturing imperfections such as:
  - Core shape (how perfectly circular in cross-section?); internal stresses on the fiber
- External stresses:
  - Radial forces (bends and twists, etc.)



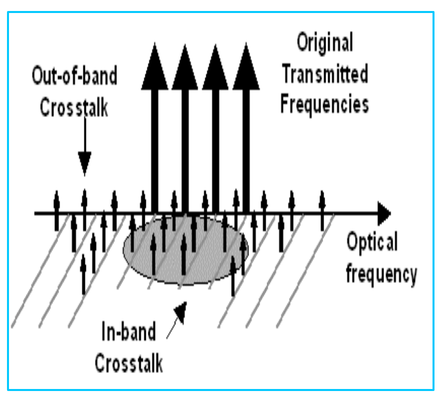
Polarization Mode Dispersion

- "Fast" axis of propagation and a "slow" axis
- Travel down the fiber is de-synchronized (out-of-phase)
- PMD presents a greater problem to system performance because it can vary with time

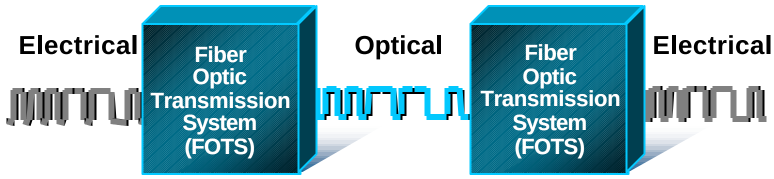


Four-Wave Mixing (FWM)

- Creates in-band crosstalk that can not be filtered
- Problem increases geometrically with
  - Number of ls
  - Spacing between ls
  - Optical power level
- Chromatic dispersion minimizes FWM



Fiber Networks

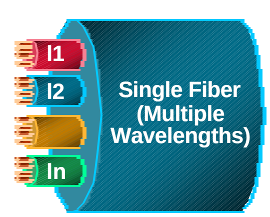


- A basic fiber optic system consists of
  - A transmitting device, which generates the light signal
  - An optical fiber cable, which carries the light
  - A receiver, which accepts the light signal transmitted
- Single time-division multiplexed information stream
  - 2.5Gbps (OC-48/STM-16) is current state of the art
  - 10Gbps (OC-192/STM-64) is next generation

Fiber Networks

- Time division multiplexing
  - Single wavelength per fiber
  - Multiple channels per fiber
  - 4 OC-3/STM1 channels in OC-12/STM4
  - 4 OC-12/STM4 channels in OC-48/STM16
  - 16 OC-3/STM1 channels in OC-48/STM16

- Wave division multiplexing
  - Multiple wavelengths per fiber
  - 4, 16, 24, 40 channels per system
  - Multiple channels per fiber



TDM and DWDM Comparison

- **TDM (SONET/SDH)**

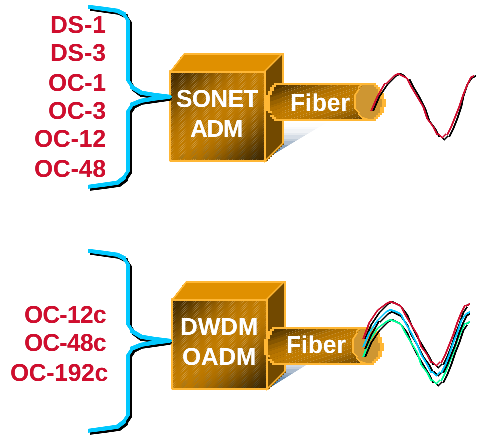
  Takes sync and async signals and multiplexes them to a single higher optical bit rate

  E/O or O/E/O conversion

  (D)WDM

  Takes multiple optical signals and multiplexes onto a single fiber

  No signal format conversion



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SONET Optical Carrier (OC) and SDH Synchronous Transport Module (STM) Levels

Optical Level	Electrical Level	Line Rate (Mbps)	Payload Rate (Mbps)	Overhead Rate (Mbps)
OC-1	STS-1	51.840	50.112	1.728
OC-3/STM-1	STS-3	155.520	150.336	5.184
OC-9/STM-3	STS-9	466.560	451.008	15.552
OC-12/STM-4	STS-12	622.080	601.344	20.736
OC-18/STM-6	STS-18	933.120	920.016	31.104
OC-24/STM-8	STS-24	1244.160	1202.688	41.472
OC-36/STM-13	STS-36	1866.240	1804.032	62.208
OC-48/STM-16	STS-48	2488.320	2405.376	82.944
OC-96/STM-32	STS-96	4976.640	4810.752	165.888
OC-192/STM-64	STS-192	9953.280	9621.504	331.776

SONET Overhead is 3% independent of Data Rate

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The World Before SONET/SDH

- No multivendor interworking = increased network costs
  - Multiple types of equipment and interfaces needed for carrier interconnections
  - No standardization of network design (protection, facility size, etc.)
  - No centralized network management and alarming

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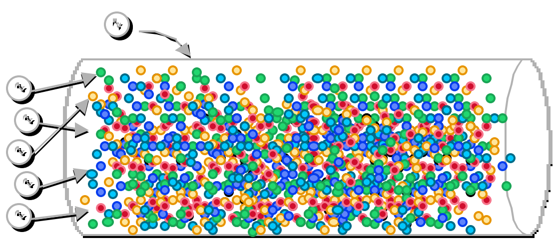
The World After SONET/SDH

- **Standard interfaces for multiplexing of high-rate digital signals**
  - **Simplification of carrier-carrier interconnection, reduced interconnect cost**
  - **Simplification of network design**
  - **Integrated overhead for standardized messaging and alarming**
  - **Reduced equipment cost**

Multiplexing: Before and After SONET

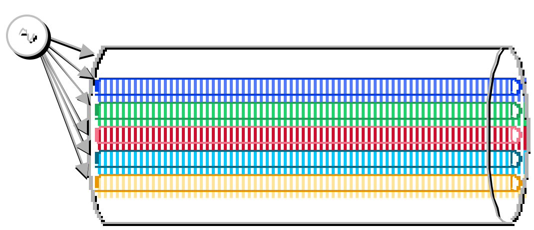
Pre SONET

Bit Interleaved
Proprietary by Vendor
Each Tributary Asynchronous
Entire Payload Demultiplexed to Access Tribs
Expensive Equipment Design

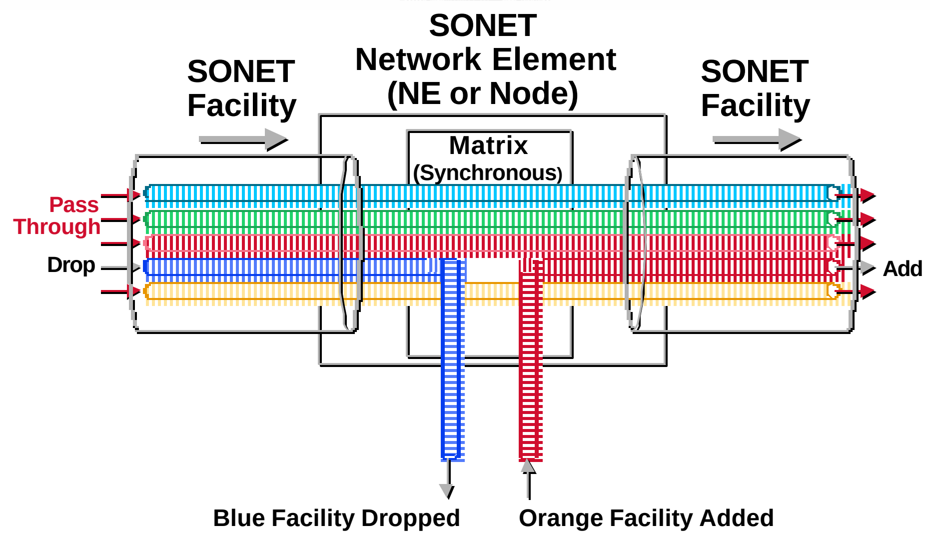


Post SONET

Byte Interleaved
Defined Framing and Rates
Each Tributary Synchronous
"Add-Drop" of Payloads without Demultiplexing
Simplified Equipment Design

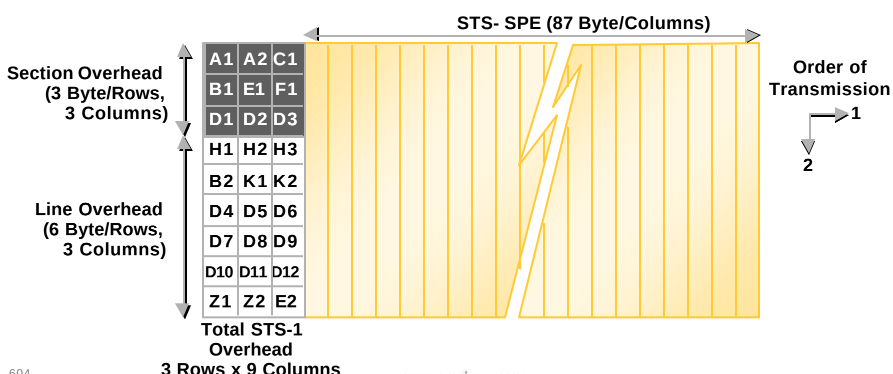


SONET Simplifies Networking of Circuits



Synchronous Transport Signal—Level 1

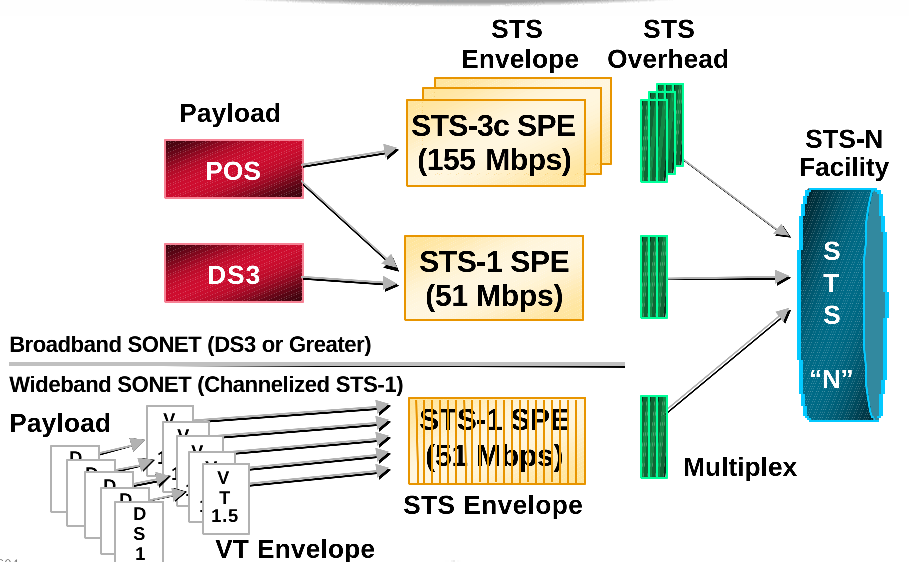
- **Basic building block—SONET STS-1 frame**
  - **3 columns of SONET overhead (x9, byte rows) = 27 bytes**
  - **87 columns of STS-1 "Synchronous Payload Envelope" (x9, byte rows) = 783 bytes**
  - **125 microseconds/frame = 51.84 Mbps**



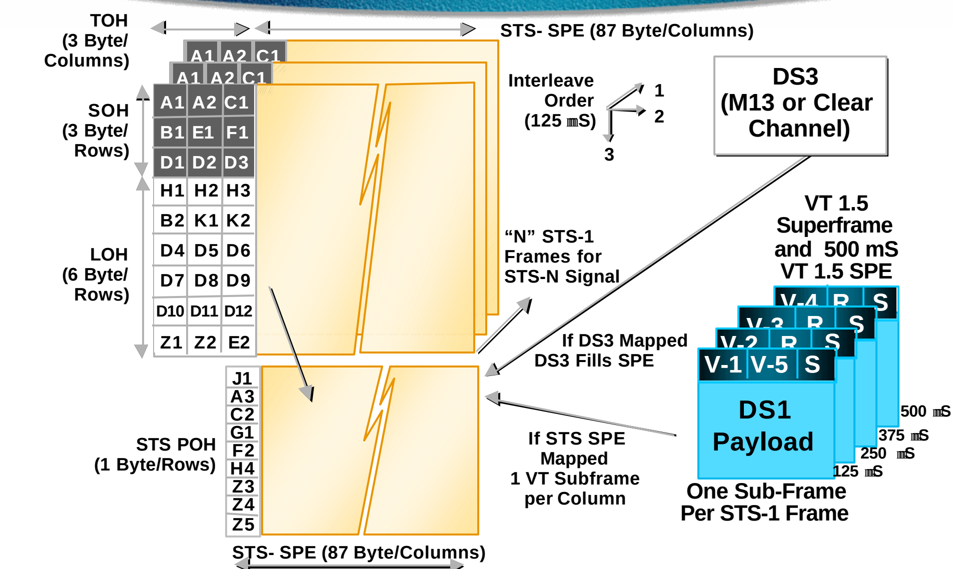
SONET Multiplexing Hierarchy

- STS-1 signals can be wideband or broadband
  - Wideband = Channeled with VT 1.5s containing DS1s
  - Broadband = High-rate DS3 and concatenated STS-1s
- VT mapped STS-1s are designed for transport and switching of sub-STS-1 rate payloads
- STS-1s can be concatenated to create higher-speed payloads
  - STS-3c, STS-12c, STS-48 for backbone data transport applications
- STS-1s are multiplexed together to create the transmitted payload
  - STS-N = N multiplexed STS-1s
  - Can intermix broadband and wideband STS-1s within multiplexed STS-Ns

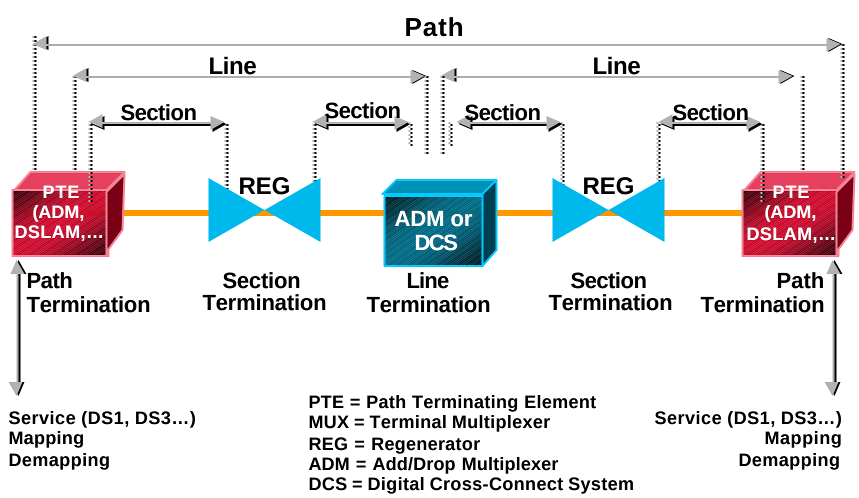
Wideband SONET and Broadband SONET



More SONET Multiplexing



SONET Overhead Layers



SONET Overhead Byte Designations

Transport Overhead

Section Overhead	Framing A1	Framing A2	Trace/ Growth STS ID J0/Z0
	BIP-8 B1	Orderwire E1	User F1
	Section Data Communication Channel D1	D2	D3
Line Overhead	Pointer H1	Pointer H2	Pointer H3
	BIP-8 B2	APS K1	APS K2
	Line Data Communication Channel D4	D5	D6
	D7	D8	D9
	D10	D11	D12
	Sync Status/ Growth S1/Z1	REI/ Growth M0 or M1/Z2	Orderwire E2

STS-1 SPE Path Overhead

Trace J1
BIP-8 B3
Signal Label C2
Path Status G1
User F2
Indicator H4
Growth Z3
Growth Z4
Tandem Connection Z5

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STS-N Section Overhead

Framing A1	Framing A2	Trace/Growth STS ID J0/Z0
BIP-8 B1	Orderwire* E1	User* F1
Section Data Communication Channel* D1	D2	D3

*Only Used in the First STS-1 of an STS-N

Framing A1+A2	16 Bits Identifying the Start of STS-1 Frame
Trace/Growth J0/Z0	Carries the Binary Number of STS-1 # within STS-n Frame and Section Trace Function (Not Yet Supported)
BIP-8 B1	Provides Error Monitoring Section for All Bits in Previous STS-N
Orderwire E1	Local Orderwire, All NEs
User F1	Optional Set aside for Vendor Implementation
D1+D2+D3	Provides Data Communication Channel between NEs to Carry System-System, System-OSS Messaging

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STS-N Line Overhead

Pointer H1	Pointer H2	Pointer H3
BIP-8 B2	APS* K1	APS* K2
D4	Line Data Communication Channel* D5	D6
D7	D8	D9
D10	D11	D12
Sync Status/ Growth S1/Z1*	REI/Growth* M0 or M1/Z2	Orderwire* E2

*Only Used in the First STS-1 of an STS-N

Pointers H1+H2	Point to Start of STS-1 SPE in STS-1s, Also Indicates Concatenation
Pointer Action H3	Positive/Negative Stuff Bytes
BIP-8 B2	Provides Error Monitoring of Section for all Bits in Previous STS-N
APS K1+K2	Used for Line Automatic Protection Switching Protocol

DCC D4-D12	Line DCC, Rarely Used (Vendor Specific)
Synchronization S1	Used for Synchronous Status Messaging (SSM) Protocol
REI/Growth M0/M1/Z2	Used for Remote Error Indication and Far-End Block Error
Orderwire E2	DS0 (Generally Voice) Express Orderwire

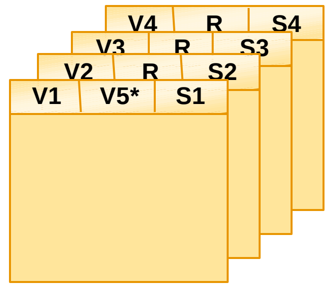
STS-1 SPE Path Overhead

Trace J1	Used as a Path Trace Generally Used to Identify Path End-Points (Circuit ID)
BIP-8 B3	Used for Synchronous Status Messaging (SSM) Protocol
Signal Label C2	Identifies Contents of STS-1 SPE (DS1/VT 1.5, DS3, ATM, etc…)
Path Status G1	Used for Remote Defect Indication and Far-End Block Error
Growth Z3–Z4	Unused
Tandem Z5	Unused in US Applications

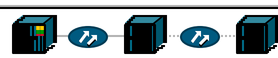
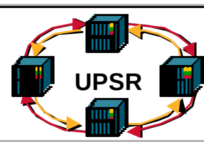
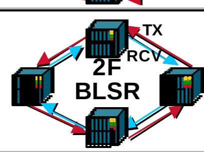
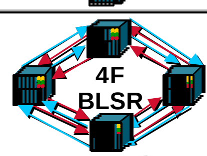
Path Overhead
Trace J1
BIP-8 B3
Signal Label C2
Path Status G1
User F2
Indicator H4
Growth Z3
Growth Z4
Tandem Connection Z5

VT 1.5 SPE Path Overhead

Pointer V1 and V2	V5 Is Floating in the Sub-frame V1 and V2 Point to Its Location
Pointer Action V3	Used to Adjust Sub-frame When Pointer Justification Is Required
Unused V4	Identifies Contents of STS-1 SPE (DS1/VT 1.5, DS3, ATM, Etc…)
PSL, FEBE, STAT V5	Error Checking, VT Path Signal Label Path Status, BIP-2, RDI
Reserved R	Unused
Stuff S1–S4	Used for DS1 Timing Variations and Adjusting DS1 Timing in VT 1.5



SONET Network Configurations

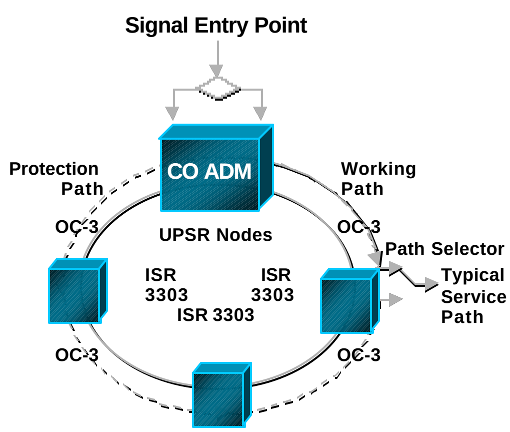
Point-to-Point		Two Nodes, Terminal Mode
Linear		Up to 16 Nodes, ADM
Unidirectional Path Switched Ring		All Traffic Homing to a Central Location
Two Fiber Bidirectional Ring		Traffic with Neighboring Pattern, Reusable Bandwidth
Four Fiber Bidirectional Ring		Traffic with Neighboring Pattern, Reusable Bandwidth

SONET Line Automatic Protection Switching (APS: Per Bellcore GR-253)

- SONET line APS protects the entire facility at the line layer
  - Monitors point-to-point status of a SONET STS-N line
  - Supports one-for-one protection of the line (fiber) facility
    - Also supports 1:N protection, N<=16
- Uses K1 and K2 for APS protocol switching
- Used in SONET spur applications
  - Spur off of SONET network
  - Spur off of SONET high-speed applications

OC-3 Unidirectional Path Switched Ring (UPSR: Per Bellcore GR-1400)

- Characteristics of a UPSR ring
  - Traffic pattern homing to a central point—bandwidth used cannot be reused
  - Can be configured to switch on VT or STS status
  - Survivable closed-loop transport architecture
  - Duplicate signals protect against cable cuts and node failures
  - Deployed in access networks terminating at a CO ADM



UPSR in Normal State

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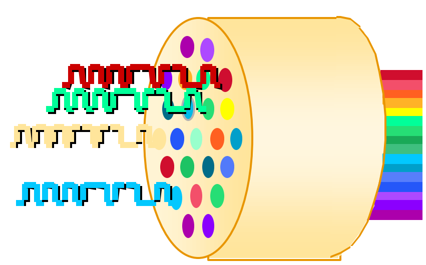
Dense Wave Division Multiplexing Provides Fiber Gain

- 16 channel x 2.5Gbps = 40Gbps
- 24 channel x 2.5Gbps = 60Gbps
- 40 channel x 2.5Gbps = 100Gbps
- 80 channel x 2.5Gbps = 200Gbps

- 4 channel x 10Gbps = 40Gbps
- 16 channel x 10Gbps = 160Gbps
- 128 channel x 10Gbps = 1280Gbps



- Multiplexed wavelengths can be amplified as one composite signal using Erbium Doped Fiber Amplifiers (EDFAs)
- Fiber non-linearities such as attenuation and dispersion impose limits on speed and distance

DWDM Economics

Example:

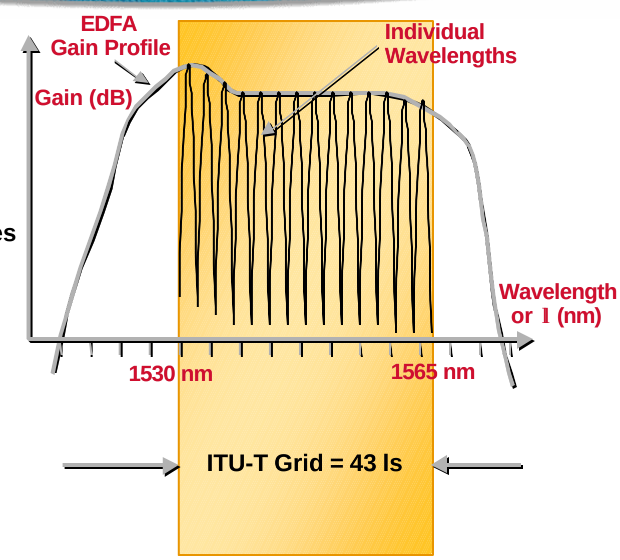
- **Laying new fiber costs $100,000/mile (trench) and $10,000/mile (duct)**
- **Cheyenne to Omaha**
  - **DWDM equipment costs $17 million**
  - **Laying new fiber costs $190 million**

Wave Division Multiplexing Evolution

- **Early WDM**
  - **Wide-band two window (1310nm, 1550nm)**
- **"2nd Generation" WDM**
  - **400+GHz spacing**
  - **Two to four channels in 1550nm window**
- **Dense WDM systems**
  - **100 to 200GHz spacing**
  - **Eight to 16 channels in 1550nm window**
- **Next Generation Dense WDM systems**
  - **Narrower spacing; 50GHz spacing**
  - **Wider amplifiers (L-band, C-band)**
  - **40 to 160 channels in 1550nm window**

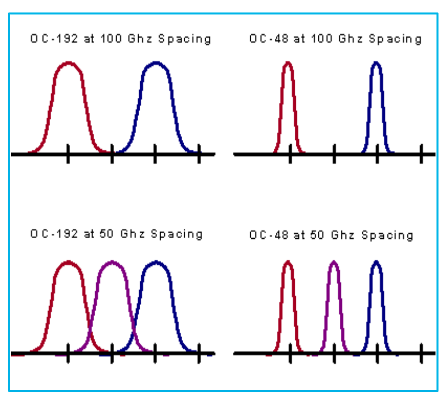
Current DWDM Spectrum

- Flat gain across 30 nm window (one EDFA)
- Standard
  - ITU-T grid specifies 100GHz spacing (1.6nm) or 50GHz spacing (0.8nm)
- Future
  - Other windows?
  - Red/blue band?

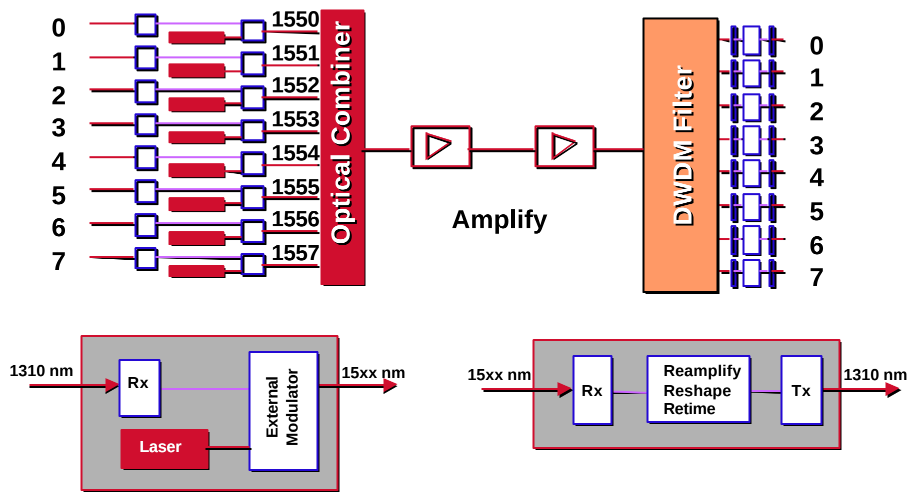


Channel Spacing

- **Increased densities**
  - Decrease l spacing
- **Problems**
  - Wavelength tolerance
  - Filter technology

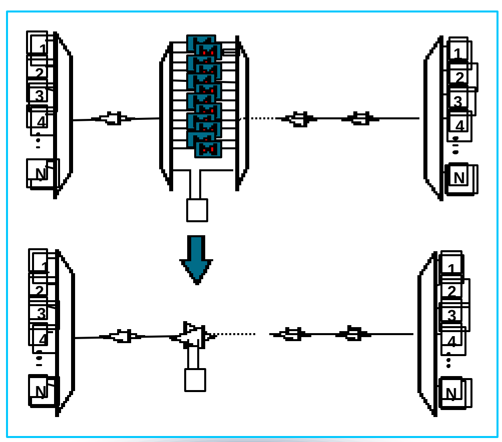


DWDM System Architecture



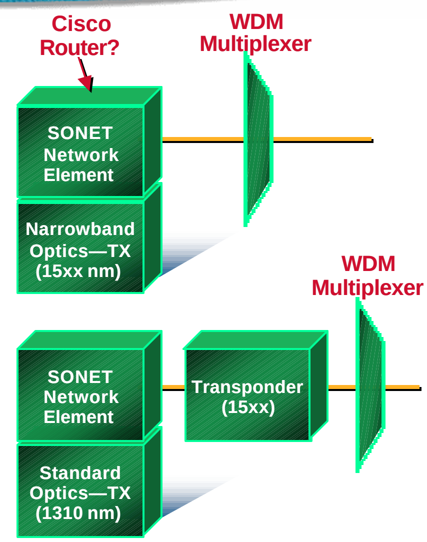
Optical ADM

- Similar to SONET ADM except switches ls
- Extends point-to-point connection to add/drop at an intermediary site
- Available in fixed configuration only
- No standards



Where to Put the Laser?

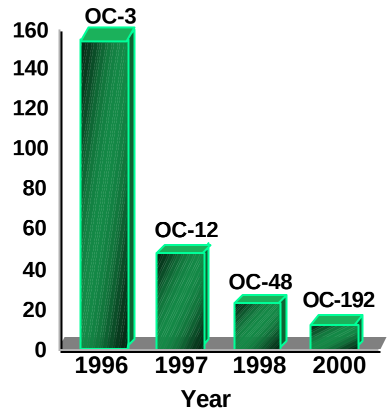
- **Integrated**
  - Eliminate second laser
  - Possibly reduces costs
  - Possibly proprietary system
- **Open**
  - Allows any digital optical input w/o SONET encapsulation

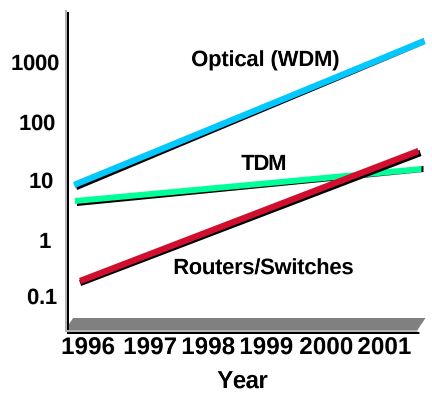


Agenda

- **Introduction**
- **Introduction to Optical Technologies**
  - Fiber Optics
  - SONET/SDH
  - DWDM
- **Optical Internetworking**
- **Summary**

Innovation Is Driving Cost of Networking Down

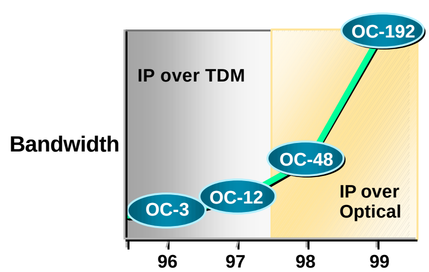


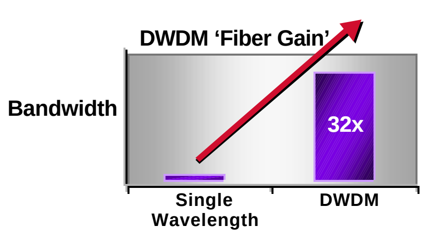


Source: Ryan, Hankin and Kent and Internal Data

Optical Internetworking IP + Optics

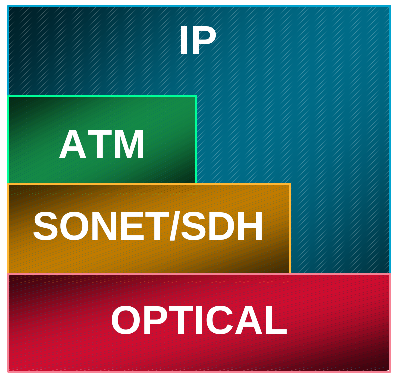
- Optical internetworking is the integration of internetworking and optical technologies





Lowering the Cost of Network

- **Reducing unnecessary layers of equipment significantly**
  - **Lowers equipment cost**
  - **Lowers operational cost**
  - **Simplifies architecture**



Benefits of Optical Internetworking

- **Increased capacity to switch huge volumes of packet-based information**
- **Lowers cost by eliminating unnecessary layers of equipment**
- **Maintain and enhance reliability to handle most demanding requirements**
- **Improved flexibility to support yet unimagined IP-based applications and services**

Cisco GSR 12000 Building Optical Internets Today!

- Cisco 12000 GSR family
- Carrier-class architecture
- SONET/SDH integration
- Premier IP-routing software
- Market-share leader
- Industry-leading cost/performance

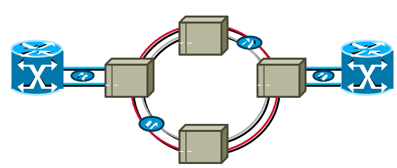
UUNET Sprint GTE Deutsche Telekom AOL.COM TIME WARNER MediaOne DIGEX

Datamation Product of the Year, Apr. '98

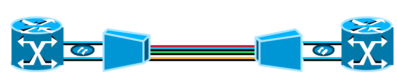
COMNET New Product Award, Jan. '98

Examples of Optical IP Backbones Being Deployed Today

Connect to tributary interfaces on SONET/SDH muxes (OC-3c/STM1c to OC-48c/STM16c)

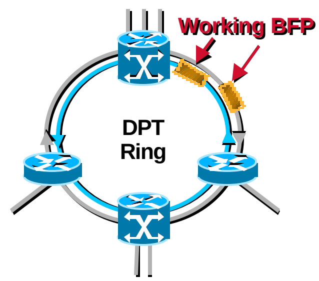


Connect to transponder-based DWDM system (typically OC-12c/STM4c or OC-48c/STM16c)



Examples of Optical IP Backbones Being Deployed Today

Interconnect GSR directly over dark fiber with regenerators to extend the distance of LR interfaces (typically OC-48c/STM16c)



- **IP-based packet ring using Dynamic Packet Transport (DPT) available at OC-12c/STM4c today**

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Session 604

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