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9.0 Fiber Systems

Objectives

This section will:

- Look at long distance fiber links
- Discuss SONET
- Introduce Nortel's FiberWorld
- Consider FTTC vs. FTTH

Some of the major world players developing fiber systems include:

Lucent (USA)

Alcatel (France)

Nortel (Canada)

Huawei (China) http://www.huawei.com/

Some interesting tutorials can be found at:

Minimum Reading

Optical Networks by Alcatel

An Introduction to the Optical Internetworking Forum

Optical Access by Luxn

Long Haul Systems

Long haul trunks were the first application of optical fiber to gain universal acceptance. Three alternate methods are coax (copper), terrestrial microwave and satellite. While microwave towers can be used to bridge relatively small bodies of water, cables or satellites are needed to span oceans.

Telegraph cables were first deployed in the mid-1800's and the first successful trans-Atlantic cable was laid in 1858. For 100 years copper submarine cables were the principle means of communication between North America and Europe. In the 1960's satellites gained ascendancy but today fiber cable dominates.

Fiber cable has some significant advantages over satellite technology:

- Fiber systems can be repaired, geo-stationary satellites cannot
- Fiber systems have a slightly longer life expectancy
- Fiber systems can be upgraded while in service
- Fiber deployment has a lower risk than launching a satellite
- Fiber propagation delay is significantly lower than satellites

Notes

9.1 Long Haul Land Systems

GTE Fiber Backbone http://www.bbn.com/infrastructure/gni.htm

The United States has deployed enormous amounts of fiber cable to support:

- PSTN interconnect
- Internet backbone
- HFC systems for the CATV industry

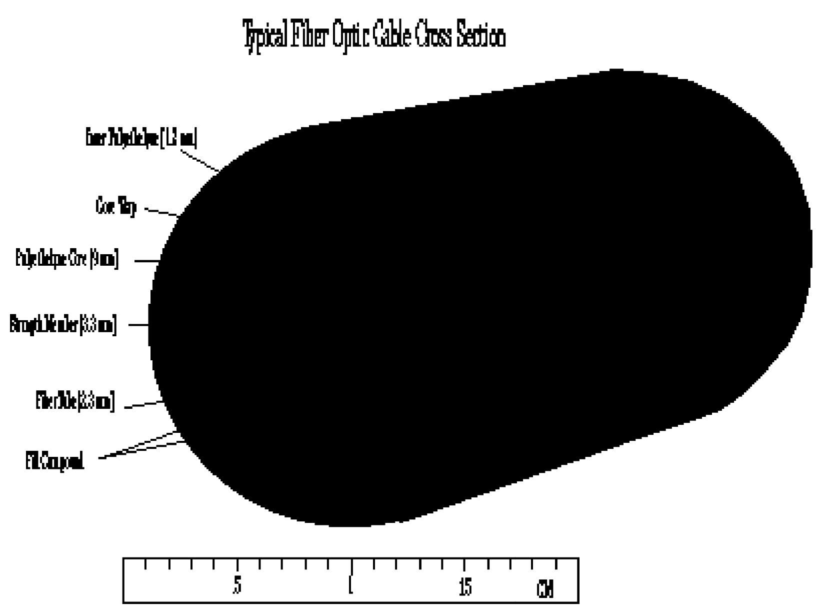
[Map of GTE fiber deployment in the USA.]()

9.1.1 Telecom Canada

The current Trans-Canada fiber system stretches some 4100 miles and includes under water links to PEI and Newfoundland. The cable is buried at a minimum depth of 5 feet in most places. The cable is buried 2 feet in rocky areas, but over major rivers such as the Thompson, it is 6 feet below the riverbed.

Eight fibers are reserved for Trans-Canada traffic, with additional fibers are used for toll traffic from the participating operating companies.

The cable has a Kevlar strength member surrounded by a star shaped polyethylene core, which can support up to 5 fiber tubes. Each fiber tube can contain up to 6 fibers. The cable has multiple layers of protection, but in avalanche prone areas, it was also encased in an 8 inch steel conduit.



The fiber initially operated at 565 Mbps and provided up to 8064 voice circuits per pair. The repeaters are spaced at about 30 mile intervals, except in BC where a different glass was specified allowing 50 mile spacing. The repeaters are housed in small buildings containing 8 hour battery backup and an auto standby diesel generator.

In case of a failure, signals can be switched to spare fibers or to both of the trans-Canada digital microwave systems and the Telesat Canada satellite system. The entire system is monitored throughout the country by provincial telco operating centers and centrally by the National Network Operations Center in Ottawa.

Sprint Canada is installing a 60 to 100 strand single mode fiber trunk between Toronto, Ottawa and Montreal. This represents twice the capacity in the existing cables. Sprint will use Alcatel transmission equipment, which is capable of operating at OC-48. The initial application is to create multiple private line networks operating at DS-1 and DS-3 rates.[1]

9.1.2 CA*net 3

Minimum Reading

http://www.canet3.net/

http://www.canet2.net/

www.canarie.ca

CANARIE Inc. is an optical Internet for research companies and universities.

It will initially deploy an 8 wavelength OC-192 fiber and will run in parallel with the existing CA*net2 ATM network. The network will interconnect 13 GigaPOPs already connected to CA*net 2. Most of the sub networks are ATM or SONET based and ranging anywhere from DS3 to OC-48.

Some very interesting ideas can be found in the article Architectural and Engineering Issues for Building an Optical Internet.

CA*net 3 Canada' s National Optical Internet Initiative

Map 1 Map 2 Map 3

9.1.3 Bell Nexxia

http://www.bellnexxia.com/gateway.asp

The Bell Nexxia SONET/DWDM network consists of 12 fiber strands.

Map 1

The system currently operates 16 wavelengths over two strands. This can be expanded to 32, providing a capacity of OC-192.

1 *Fiber Networks Link Canada's Business Routes*, Lightwave, January, 1995

The system uses diverse routing, backup PoPs, and redundant equipment to ensure reliability. The Nortel backbone uses a BLSR[†] architecture. In the event of a cable cut, the ring can self-heal in 50 milliseconds.

In large urban centers, an OC-48 SONET ring is deployed.

The IP network uses Packet Over SONET as opposed to ATM and Frame Relay.

National IP Network National ATM Network

The network's core uses 100 Newbridge high-capacity ATM switches. The network edge uses 200 Nortel Passport switches. Local access is provided by fiber and DSL.

9.1.4 Trans-Siberian Link

It has been proposed that a Trans-Siberian link[2] spanning the former USSR and effectively creating a glass ring around the world, be constructed. Some of the features that have been identified so far include[3]:

- Inauguration expected 1995
- Length: 18,445 Km
- Estimated cost: 500 M$US
- Wavelength: 1.55 µm
- Bit rate: 565 Mbps
- Capacity: 7680 telephone circuits
- Repeater spacing: 100 Km
- Upgradeable to 2.5 Gbps

It is expected that once completed, this fiber might carry 25% of all of the fiber traffic between Europe and the Pacific region.

† Bi-directional Line Switching Ring

2 *Analysis of Prospects of Fiber Long-Distance Telephone Network,* IEEE Communications Magazine, July 1991

3 *Trans-Soviet fiber-optic communication line and global digital telecommunication ring,* Telecommunication Journal, vol. 57

9.2 Submarine Systems

There are over 300 submarine cable systems in operation throughout the world. Unlike land based systems, these must be constructed in their entirety before they are commissioned.

Submarine cables have a number of unique requirements. One of the most stringent requirements is reliability. The typical designed life span is 25 years, and over that period, it is expected that 3 ship repairs will be necessary. In most places, cable is plowed into the sea floor when in water is less than 1500 m. This minimizes damage caused by fishing vessels.

Long-haul fiber submarine cables are powered at each end by 8 - 15 KV DC at currents of up to 1.6 Amperes. This is required to power the optical repeaters.

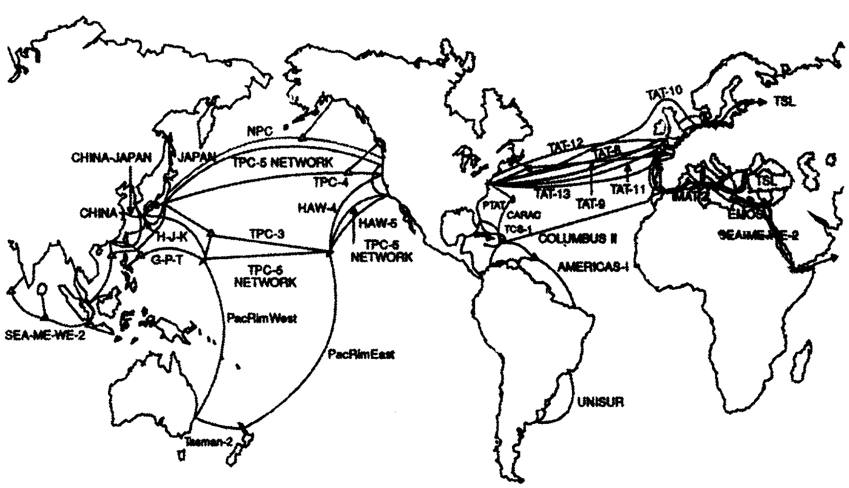
To increase reliability, each cable has spare fibers and the repeaters contain extra laser diodes. In case of a failure in a strand, the system configures itself to route around the problem.

A significant advantage of fiber over copper links is the phenomenal available bandwidth. In addition, it may be possible to upgrade a number of links by changing the associated electronics while leaving the fiber intact.

See Appendix A2 for a list of some of the major international fiber optic links.

It is now possible to transmit 160 Gbps per fiber pair, by using WDM. Each of 16 different wavelengths can currently support 10 Gbps. It is expected that this will increase to 32 Gbps in the near future.† Current technology allows the repeaters to be spaced at intervals of 300 km.

Trans-Oceanic Fiber



† Fiber Optics Online, Oct. 7, 1999

Trans oceanic fiber is an essential component to the GII† that is supposed to emerge by the year 2015, according to industry experts.

Transoceanic demand will total almost five terabits in 2004, according to Pioneer Consulting. The five-year compound annual growth rate in transoceanic demand will be 103% from 1999 to 2004.

9.2.1 TAT 12/13

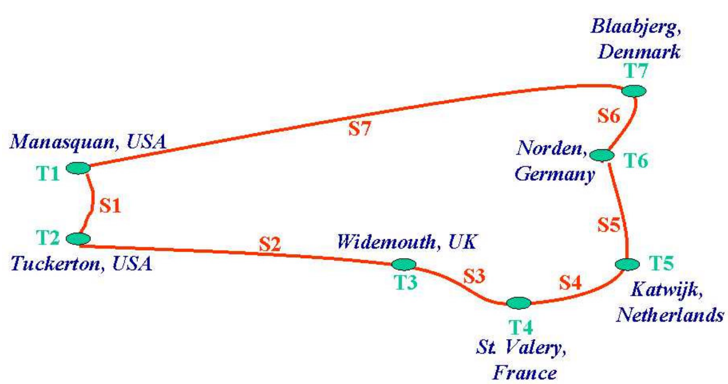
http://www.alcatel.com/submarine/refs/cibles/atln/tat1213.htm

The TAT 12/13 ring currently operates at 5 Gbps per fiber. It is expected that WDM will triple this. It went into service in 1996.

9.2.2 TAT 14

http://www.tat-14.com/

Fifty telecommunications carriers are involved in constructing the 1.5B$US TAT-14 fiber link.



It will span 15,000 km using WDM and SDH technology. The TAT-14 cable will have a total transmission capacity of 640Gbps.

† Global Information Infrastructure

9.2.3 Crossing Network

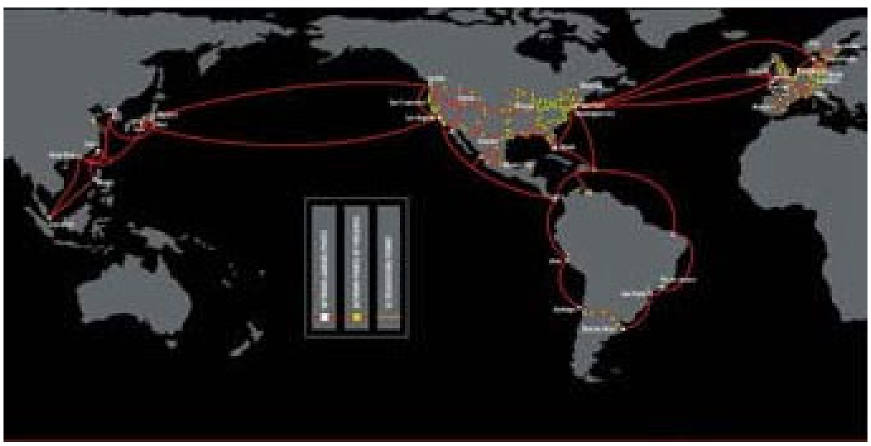
Global Crossing®

Minimum Reading

IP VPN Performance

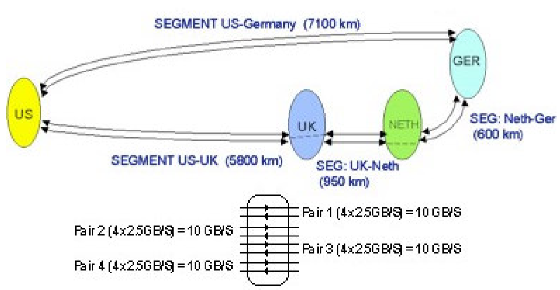
This system filed for bankruptcy protection in January 2002. It listed 12.3B$US in debt, making it the largest telecom bankruptcy in American history.

http://www.globalcrossing.com/xml/index.xml



The Crossing Network consists of: 2 cables across the Atlantic [AC1/2], one across the mid Atlantic [MAC], and one across the Pacific [PC-1].

The Atlantic Crossing cable system is an optic ring network connecting the US, UK and Germany. It is a over 14,000 km, four fiber self-healing SDH network. Each fiber pair will initially carry 4 x STM-16 payloads [2.5 Gbps]. WDM is used to provides a capacity of 10 Gbps per fiber pair.



9.2.4 Gemini

Minimum Reading

http://www.gemini.bm/

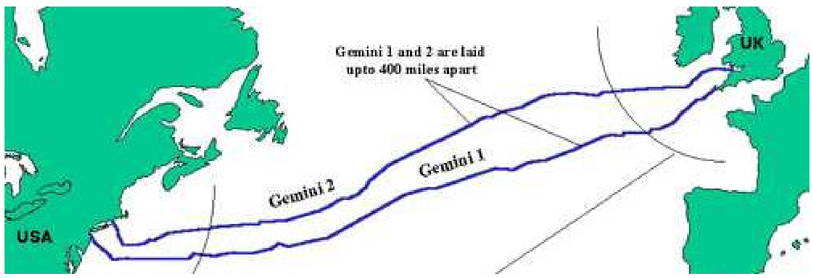
Gemini consists of three dual SDH rings:

A land ring linking London with the 2 UK cable stations

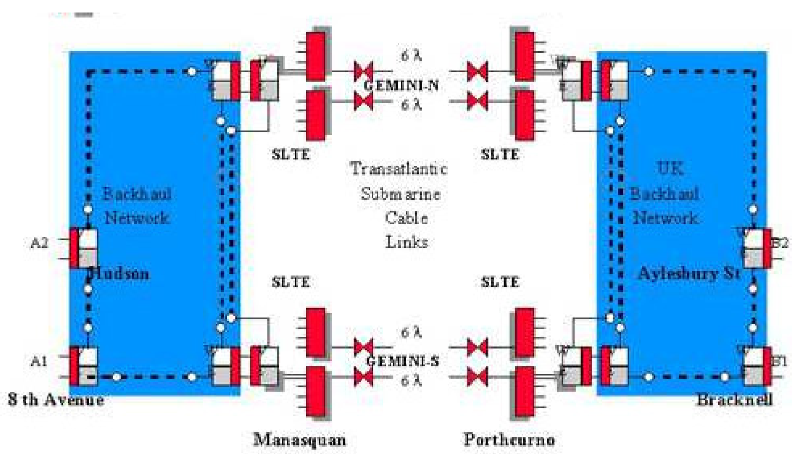
A submarine ring linking the 2 UK and US cable stations

A land US ring linking New York with the 2 US cable stations

Each of the 3 SDH rings has a capacity of 20 Gbps. Each ring is comprised of 8 individual 2.5 Gbps WDM paths. The submarine ring has a capacity of 30 Gbps.



The three rings use Add Drop Multiplexers (ADM). These inject the signal both ways round the ring from the entry point. At the exit, the better of the two signals is passed to the next ring. Thus, the network could be subjected to multiple failures without loss of service.



Note - only one STM-16 shown; there are seven more

The submarine cable has 4 non dispersion shifted optical fibers operating at 1560 nm with an attenuation of 0.2 dB/km. The fibers are loosely held in a slotted core former, with slack to provide protection against strain. The fiber is encased in a copper tube, which conducts power from the terminal stations The repeaters are powered by 1.2 amp constant current generators in the terminal stations. End to end system voltage is about 10 kV.

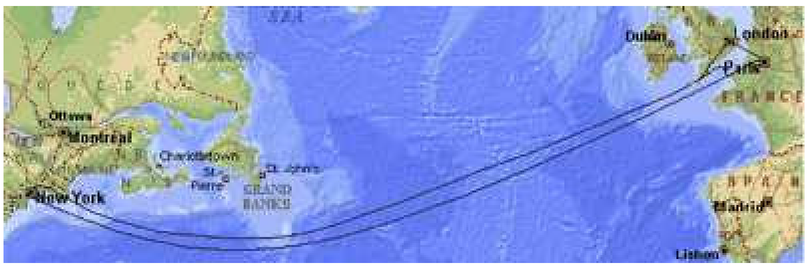
Steel wires within the copper tube provide tensile strength. The tube is surrounded by a polythene screen providing a cable diameter is just about 2 cm.

Armoring wires are applied in waters less than 2000 meters to provide greater protection against fishing boats.

Gemini uses erbium-doped repeaters with redundant lasers. They are spaced 70 km apart and provide a 12 dB gain.

9.2.5 Flag Atlantic 1

http://www.flagatlantic.com/



The Atlantic crossing consists of two fibers with an overall length of 14,500 km.

The initial 160 Gbps portion will be expandable to 1.28 Tbps.

It has been recently announced that the capacity of this system will be doubled to 2.4 Tbps. This is enough capacity to support 30 million voice circuits.[†]

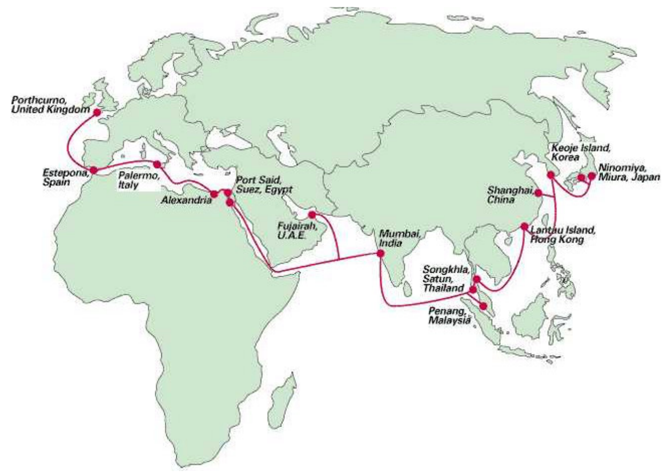
9.2.6 FLAG

http://212.161.121.200/home.asp

FLAG[†] links the UK to Japan.

† Fiber Optics Online, Oct. 27, 1999

† Fiberoptic Link Around the Globe



FLAG is currently the world's longest fiber optic cable system. Some of its features include:

- 27,300 km of cable [6,000 km buried at a minimum depth of 1.6m]
- Diversely routed land crossings - two in Egypt and two in Thailand.
- 120,000 digital circuits operating at 64 Kbps.
- Two fiber pairs - each operating at 5.3 Gbps.
- 326 erbium-doped optical amplifiers.
- Four fiber-switched branching units.

Depending on the destination, it is expected that DWDM will be used to increase the 2 wavelengths used in most of the system to a maximum of 64.

9.2.7 Africa ONE

http://www.africaone.com/

Africa ONE has 39,000 km of undersea fiber optic cable forming a ring around Africa.

Each terminal station is provided with a transmission capacity of at least one bi-directional STM-64, with the traffic managed at the E1 level. When fully equipped, this provides each station with a capacity of approximately 120,000 voice circuits.

It will link African Carriers directly to Italy, Greece, Portugal, Saudi Arabia and Spain.

_____ Notes _____

9.2.8 SEA-ME-WE 3

http://smw3.fcr.fr/

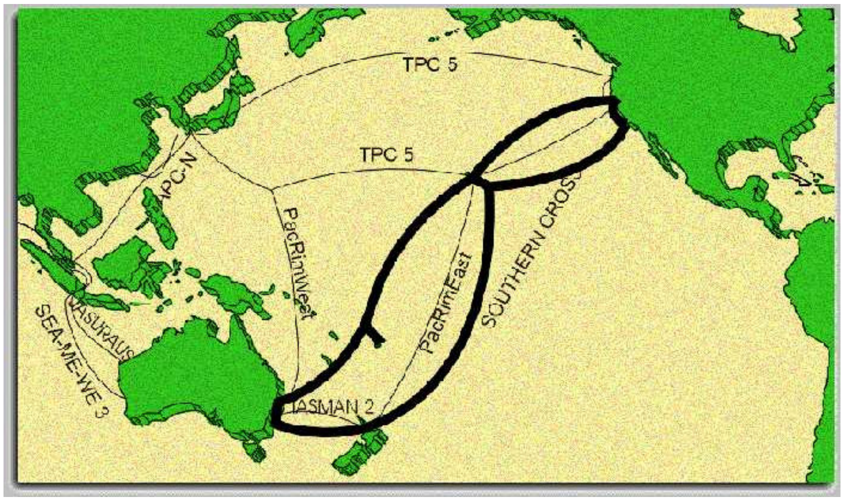
This 38,000 km cable connects 33 countries in South East Asia, the Mediterranean, and Western and Central Europe.

It has 2 fiber pairs operating at 4 x 2.5 Gbps and is expected to be upgraded t 8 x 2.5 Gbps.

9.2.9 Southern Cross

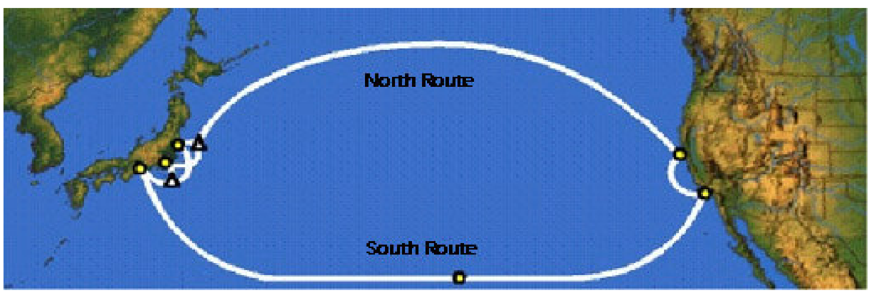
http://www.southerncrosscables.com/

Southern Cross is a 30,000 km ring. It has two fiber pairs, each with a 20 Gbps capacity. It supports SDH and WDM.



9.2.10 Japan-US Cable Network

www.japan-us.org/

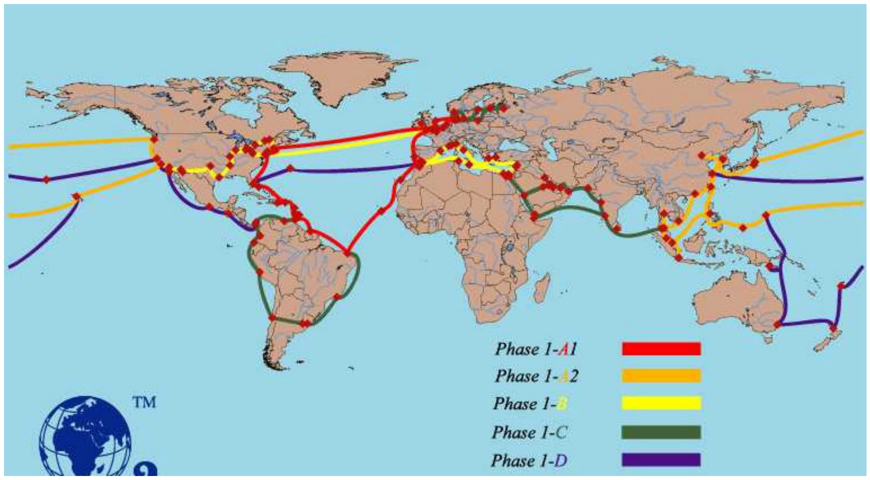


The Japan-U.S. Cable Network has 3 landing points in the United States and 3 in Japan with approximately 21,000km of 8 (4 pairs) fiber submarine cable in a self-healing ring. It will initially operate at 80 Gbps (512 STM-1s) and later at 640 Gbps (4,096 STM-1s).

9.2.11 Project Oxygen

http://www.oxygen.org/

This is a global submarine optical fiber cable network with 99 landing points in 78 countries. It is expected to have a minimum throughput of 1.28 Tbps on any cable segment.



Phase 1 of this project is expected to cost 10B$US.

9.3 SONET

Minimum Reading

SONET 101

SDH by Marconi

SONET by Nortel

SONET by Sprint

SONET by tektronix

This is an optical telecommunications standard, which falls under the broader category of Broadband ISDN.

Existing SONET Standards[4]

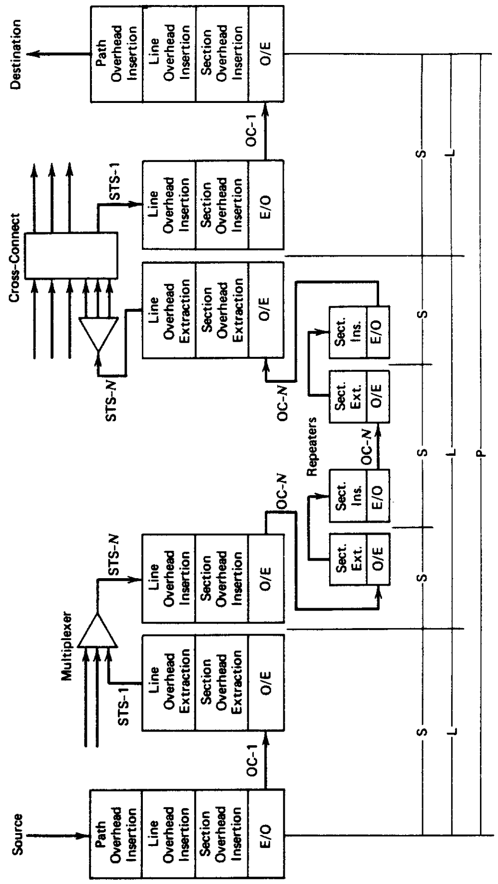
Standard	Subject
T1.105-1988	Basic Rates and Formats
T1.106-1988	Optical Parameters
T1.105-1991	Protection Switch & Synchronous Additions
TA-TSY-000253	SONET Generic Criteria
TA-TSY-000496	SONET Add-Drop

In December 1989, Bellcore started issuing draft copies of SONET technical advisories covering systems operation, survivability, ring structures, and ATM.

4 *So what's the big deal about a SONET mid-span meet?,* Telephony, January 28, 1991

Notes

SONET Overhead Layers[5]



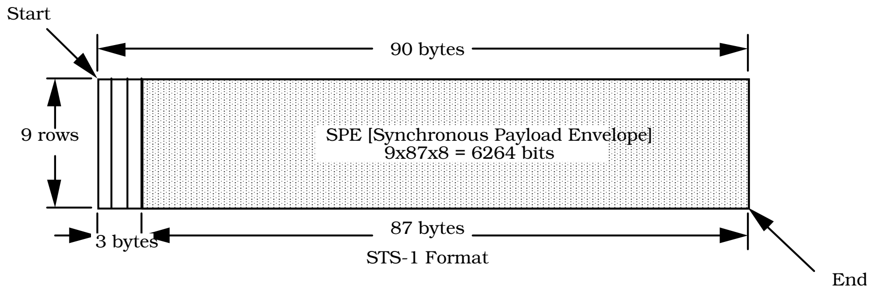
OC Level	Bit Rate [Mbps]	Payload Rate [Mbps]
OC-1	51.84	
OC-3	155.52	149.760
OC-9	466.56	
OC-12	622.08	600.768
OC-18	993.12	
OC-24	1244.16	1202.112
OC-36	1866.24	
OC-48	2488.32	2404.800
OC-96	4976.64	
OC-192	9953.28	

9.3.1 OC-1

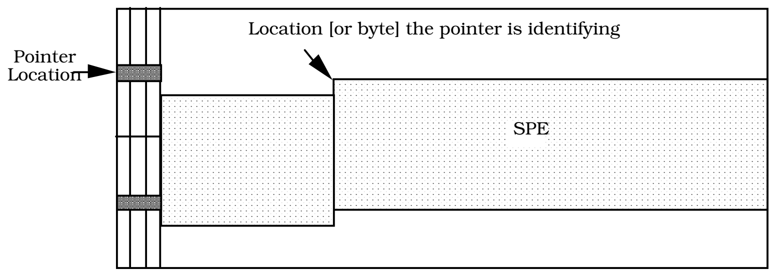
Higher order SONET signals can be obtained by byte interleaving frame aligned STS-1 signals or by concatenation. Concatenation occurs when the payload is treated as a single unit. This is denoted by placing the letter c after the rate designation. [i.e.. STS-3c]

5 *Digital Telephony* (2nd ed.), John Bellamy, Figure 8.15

STS-1 Format



STS-1 Format



STS-1 with Floating SPE Payload

SONET Overhead Channel Byte Allocation[6]

	Transport Overhead				Path Overhead
	Row	Byte 1	Byte 2	Byte 3	
Section Overhead	1	A1	A2	C1	J1
	2	B1	E1	F1	B3
	3	D1	D2	D3	C2
Line Overhead	4	H1	H2	H3	G1
	5	B2	K1	K2	F2
	6	D4	D5	D6	H4
	7	D7	D8	D9	Z3
	8	D10	D11	D12	Z4
	9	Z1	Z2	E2	TC

6 *SONET: Now It's The Standard Optical Network*, IEEE, 1989

Nomenclature:

A1 & A2	framing bits indicating the start of the frame
B1 - B2	8 bit Interleaved Parity
C1	STS-1 identification byte
D1 - D12	line data communications channel
E1 & E2	orderwire for network maintenance personnel
F1	reserved for network operation user applications
H1 - H3	header pointer
K1 & K2	automatic protection switching message channel
Z1 & Z2	reserved for future growth

In addition to these overhead bytes, SONET carries a number of STS-1 path overhead bytes, which are processed at the payload terminating equipment:

J1	trace
B3	8 bit interleaved parity
C2	signal label indicating payload type
G1	path status for maintenance purposes
F2	user channel
H4	multiframe alignment byte
Z3 & Z4	reserved for future growth
TC	tandem connection

9.2.2 OC-3

A SONET OC-3 signal is composed of three OC-1 signals. There is considerable flexibility in how this link can be structured.

Many end-users will want to continue using existing DS-1 service. When this is mapped into an OC-n signal, is called a VT1.5 [since the bit rate is approximately 1.5 Mbps]. The VT stands for virtual tributary.

Each OC-1 component can carry 28, VT1.5s [or 672, DS-0s]. An OC-3 can carry 84, VT1.5s [or 2016 DS-0s]. For basic narrowband services this is clearly overkill. However, it does raise the possibility of allowing for new services.

Of the 155.52 Mbps available on the OC-3 link, about 129 Mbps will be offered to end-users in North American.

It has been suggested that both ATM and STM can be mixed in the same STS envelope and separated by the CO at a broadband cross-connect.[7] An alternative would be to segregate ATM and STM in their own STS envelopes.

9.4 Fiber MANs

Fiber networks are being deployed in all of the major metropolitan areas of the world.

Metro Optical Networking - Bell Labs Technical Journal

An Introduction to the Optical Internetworking Forum

Optical Access by LuxN

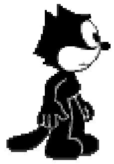
Optical Networks by Alcatel

9.6 HFC

Cornerstone Hybrid Fiber Coax

7 *Telesis* 1990 One/Two

Assignment Questions



Quick Quiz

1. Fiber cable is typically plowed [1, 2, 3] meters under the ground.
2. Most long haul optical fibers use [single mode, multimode, graded index] fiber.
3. Synchronous payload envelopes do not float. [True, False]
4. Approximately 25 Mbps on an OC-3 link is unavailable to the end-user. [True, False]
5. It is not possible to combine ATM and STM in the same payload envelope. [True, False]
6. The bit density in the AccessNode equipment bay is expected to be approximately [6, 60, 600] Gbps.
7. WDM [can, cannot] be supported on passive optical stars.
8. Propagation delay on trans-Atlantic links is [greater, less] on fiber links than on satellite links.
9. Most trans-oceanic optical fibers use [single, multi] mode fiber.
10. The typical bit rate on long haul fiber is presently about [5, 50, 500] Mbps.

Composition Questions

1. Describe the trans-Canada fiber system.
2. What is ATM (asynchronous transfer mode)?
3. Why do telecom and CATV providers use different modulation schemes over fiber?
4. What does the acronym PTAT stands for?

For Further Research

Palais, *Fiber Optic Communications*

Sandbank, *Optical Fibre Communications Systems*

Bookmarks

http://www.cmpcmm.com/cc/standards.html

http://www.nsw.siemens.de/englisch/start2e/index.html

http://www.netoptics.com/

http://www.att.com/attlabs/brainspin/fiberoptics/

SONET

http://www.nt.com/broadband/reference/sonet_101.html

http://www.tektronix.com/Measurement/App_Notes/SONET/

http://www.ans.alcatel.com/products/lw/apps/trns_sdh/trnsdh01.html

http://www.netwiz.net/~lutzj/index.htm

MONET

http://www.bell-labs.com/project/MONET/

All Optical Network Consortium

http://www.ll.mit.edu/aon/index.html

http://www.med-1.com/technical_main.htm

http://www.pirelli.com/cables/index.htm

http://www.margus.com/

http://www.alaskafiber.com/

http://www.submarinesystems.com/tssl/

http://www.corning.com/maps/index.html

Major Undersea Systems

http://www.flag.bm/

http://www.flagatlantic.com/

http://www.globalcrossing.bm/

http://globalphoton.com/

http://www.oxygen.org/

http://www.southerncrosscables.com/

http://www.japan-us.org/
http://www.tat-14.com/

Submarine Cable Systems and Developers

Alaska United
Africa ONE
ARCOS-1
Australia-Japan Cable
Concerto/Flute
Emergia
C2C (site is under construction)
Fiberweb
FLAG
FLAG Atlantic-1
Global Crossing (AC-1, PC-1, MAC, PAC, etc)
Global Photon
Guam-Philippines
Interoute/i-21
Japan Information Highway (JIH)
Lev/IC-1
Level 3 (NACS)
Maya-1
Med Nautilus
Nava Networks (Nava-1)
Onesea
Pangea
SAFE and SAT-3/WASC
SEA-ME-WE-3
Southern Cross
TAT-14
Telia (Baltic Ring/Viking Ring)
360networks (360atlantic, 360americas)

Suppliers to the Submarine Cable Industry

Alcatel Submarine Networks
Brush Wellman
Corning
Fujitsu (general site)
Fujitsu (submarine systems site)
Global Marine
KDD-SCS
NEC
Nortel
OCC
Pirelli