Evolution of fiber optic technologies

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Outline

- ***History & Background of Optical Fiber Communication***
- ***Standards &Technologies of Optical Transport***
- ***Summaries***

Big Milestone of Optical Communication

	Meman, Mayman	Gao Kun	Bell Laboratories	David Payne	Li Dingyi	Nortel
						
	The first laser	Optical fiber theory	Optical fiber system	EDFA	WDM	Coherent Technology
Year	1960	1966	1976	1989	1990	- 2008
Capacity			44Mb/s	2.5Gb/s	2.5Gb/s x 40 CH	100Gb/s x 80 CH

The Laser Was Invented in 1960, Bell Lab Developed The Commercial Laser in 1977

In 1960, American Mayman invented the first ruby laser.

In 1977, Bell Lab developed a semiconductor laser with a lifespan of 100,000 hours.

 From the public image of the network

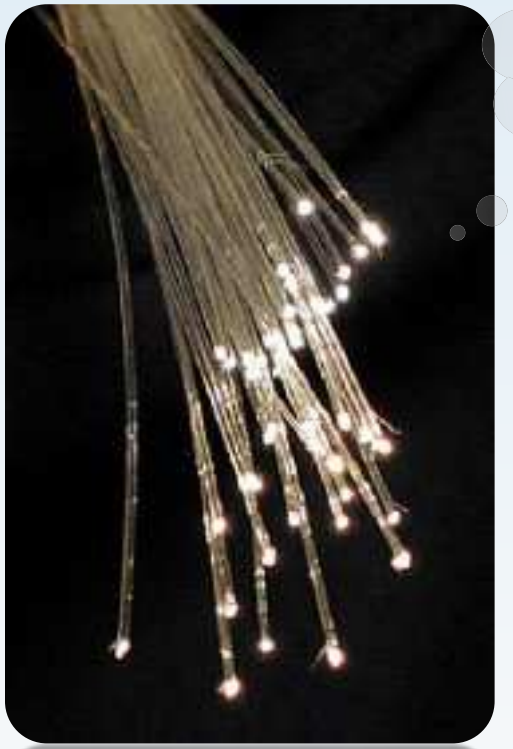
In 1966, Dr. Gao Kun Invented Optical Fiber

In 1966, Gao Kun published a famous paper "Optical Frequency Medium Fiber Surface Waveguide".

He foresaw the limit of optical fiber loss <20dB/km, and proposed the idea of optical fiber communication, which opened a new era.

Gao Kun, "Father of Optical Fiber" won the Nobel Prize in Physics in 2009.

From the public picture of the network



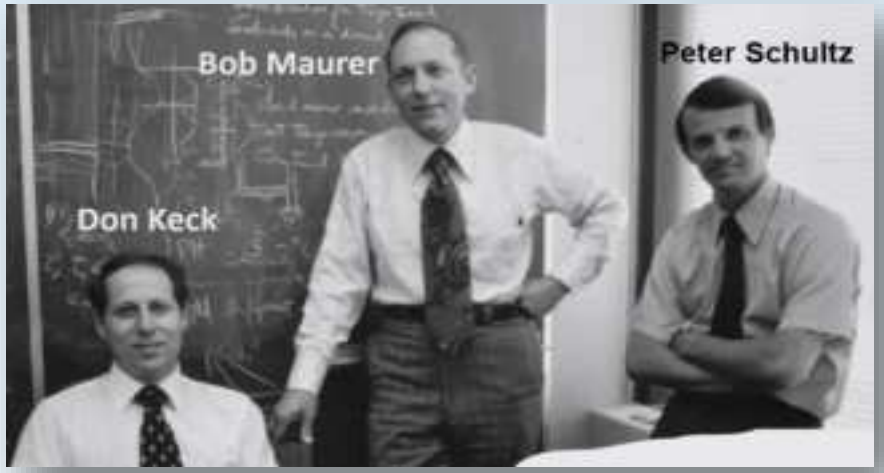
"In the next 1,000 years, it will be difficult to find a transmission medium that replaces fiber!"

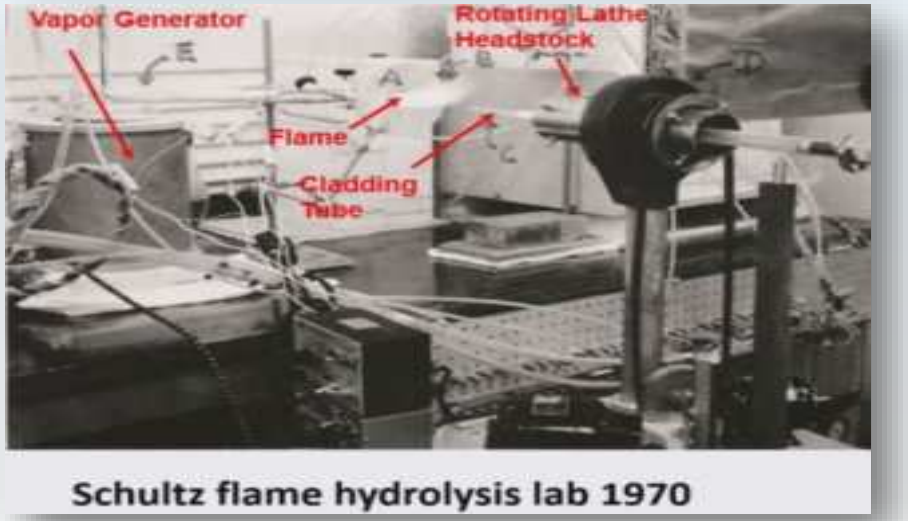
Ultra-high bandwidth (dozens of thz)

Energy saving and environmental protection (sand)

Physical security (Anti-electromagnetic interference)

Four Years Later, The First Fiber Was Born.





Schultz flame hydrolysis lab 1970

- In 1970, Corning developed the world's first practical optical fiber based on Dr. Gao Kun’s paper.
- Heat treatment fiber (1000C) technology is used to greatly reduce the fiber loss from > 10000 dB/km to 17 dB/km.

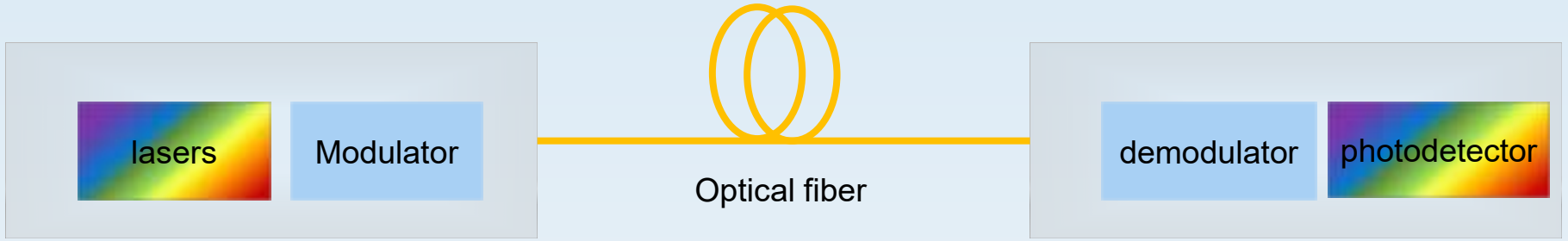
Corning continues to be a leader in fiber optics for 50 years

From the public image of the network

Mainstream Optical Fiber Types

Category	Features and Application Scenarios		Major countries	Optical cable construction period
G.652D	Global mainstream	Low loss, suitable for long-haul WDM	China, USA, Europe	Late 1980s to present
G.653	Stepping into the end	Large non-linear loss, not suitable for WDM	Japan and Latin America	•In the early 1980s, the multiwave system was not put into commercial use. •New optical cables have been routed to G.652 in recent years.
G.654E	For ultra-long	Inherited G.652, with minimum loss and applicable to long-haul WDM.	China	Preferred ultra-long haul After 2018

In 1975, the World's First Commercial Optical Fiber Communication System

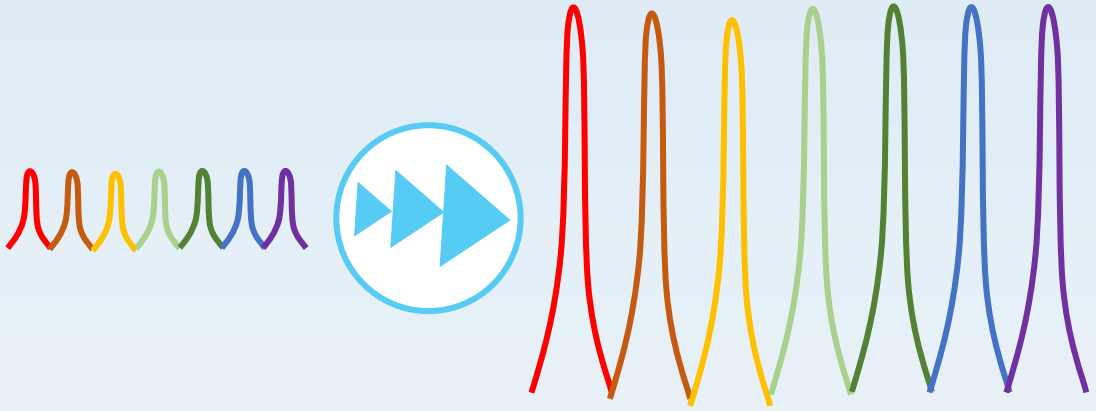


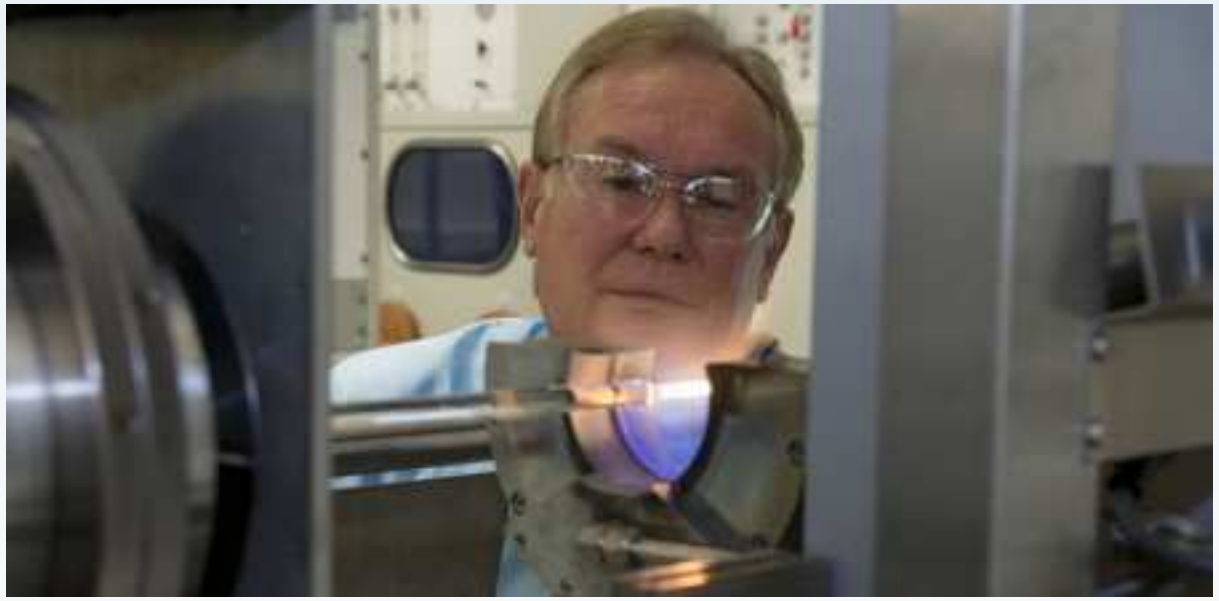
From the public picture of the network

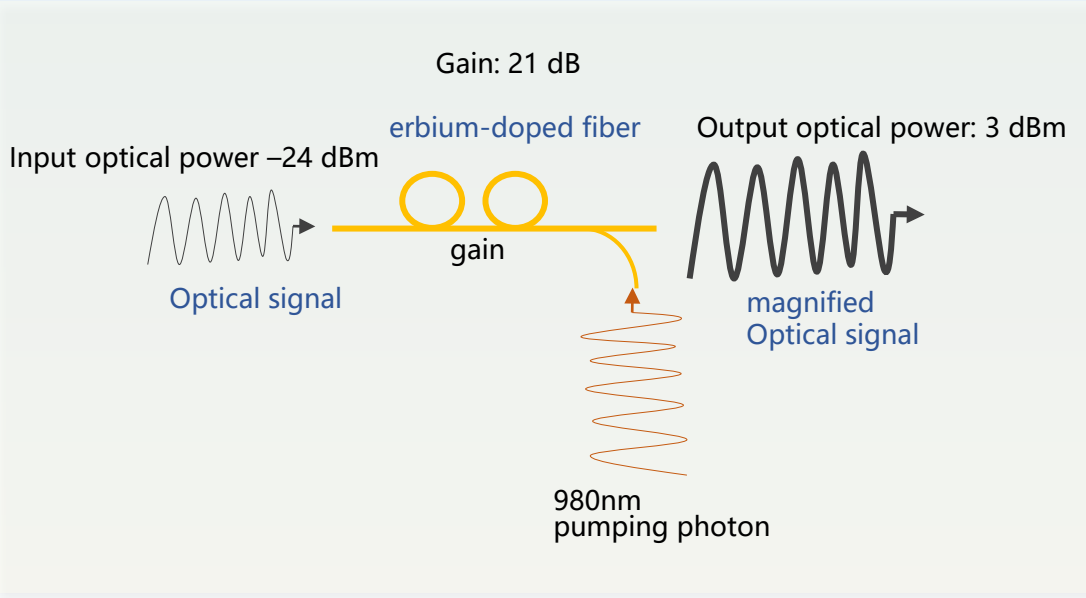
In 1975, AT&T/Bell deployed the world's first commercial optical fiber communication system (45 Mbit/s@10 km) in Chicago, opening a new era of large-capacity communication.

In 1985, The EDFA Optical Amplifier Was Invented For Optical Regeneration

- In 1985, Professor David Payne invented the EDFA.
- This breakthrough invention has become an important cornerstone of long-distance optical transmission systems.

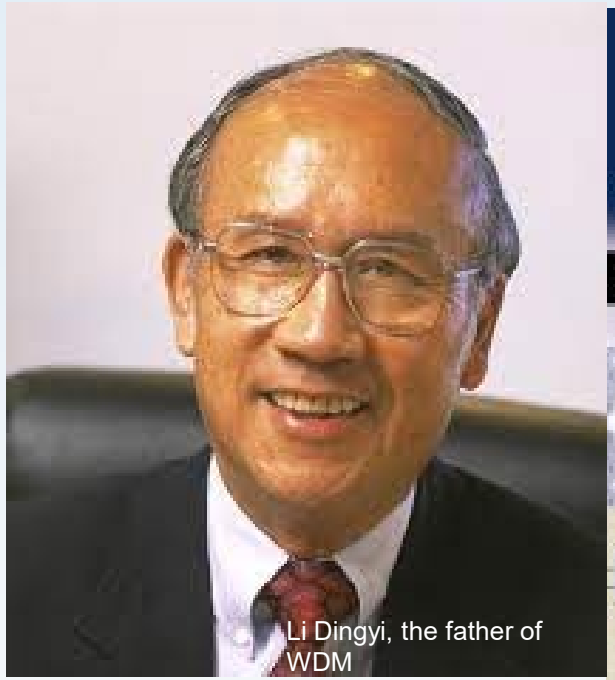


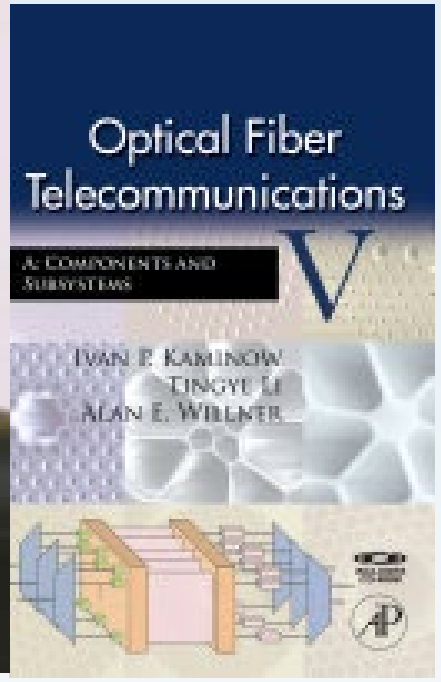




In 1991, The First Commercial WDM System Was Developed

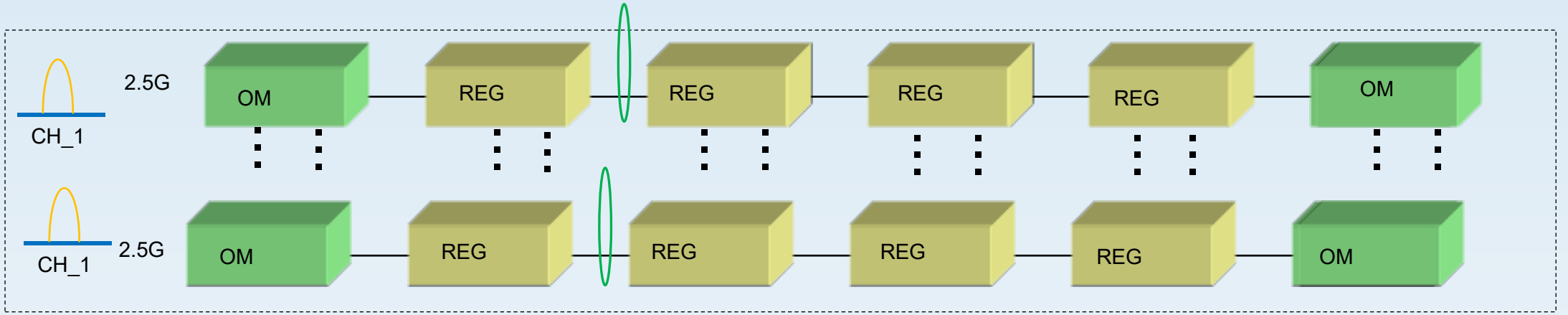
- In 1991, Li Dingyi and his team developed the world's first commercial WDM system (8 x 2.5G/CH) in Bell Labs.
- Then, One optical fiber from one PDH/SDH channel to more than 80 WDM channels, leading the technological revolution in the optical communication field

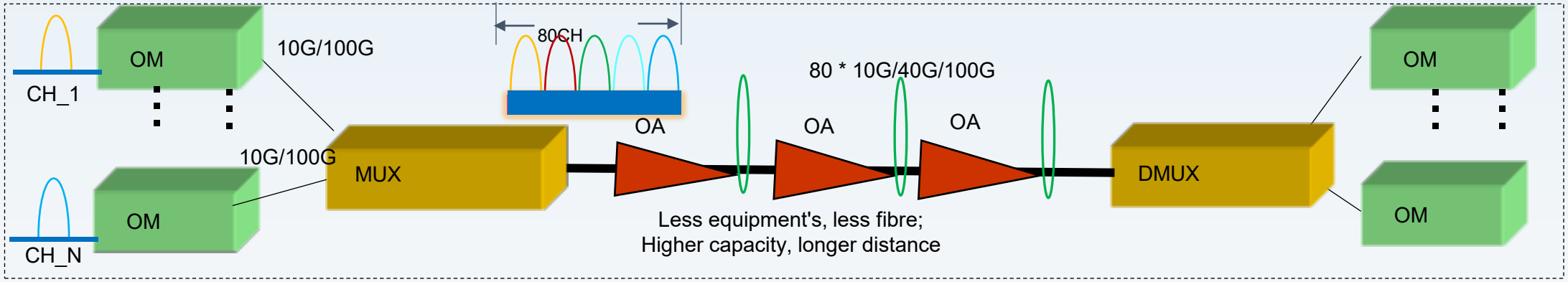

Li Dingyi, the father of WDM



Wavelength Division Multiplexing

Optical Transmission: From Parallel Mode to WDM

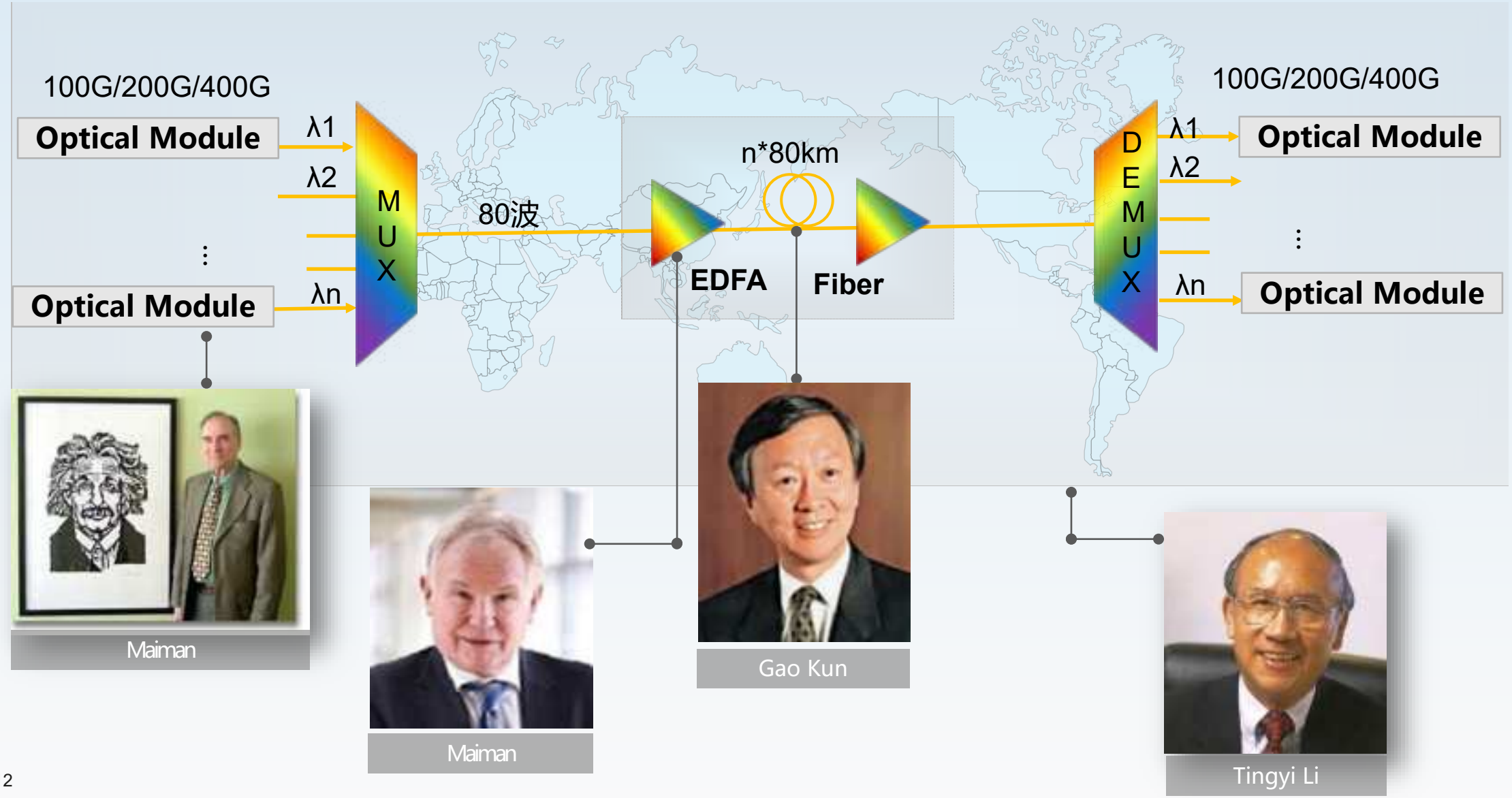




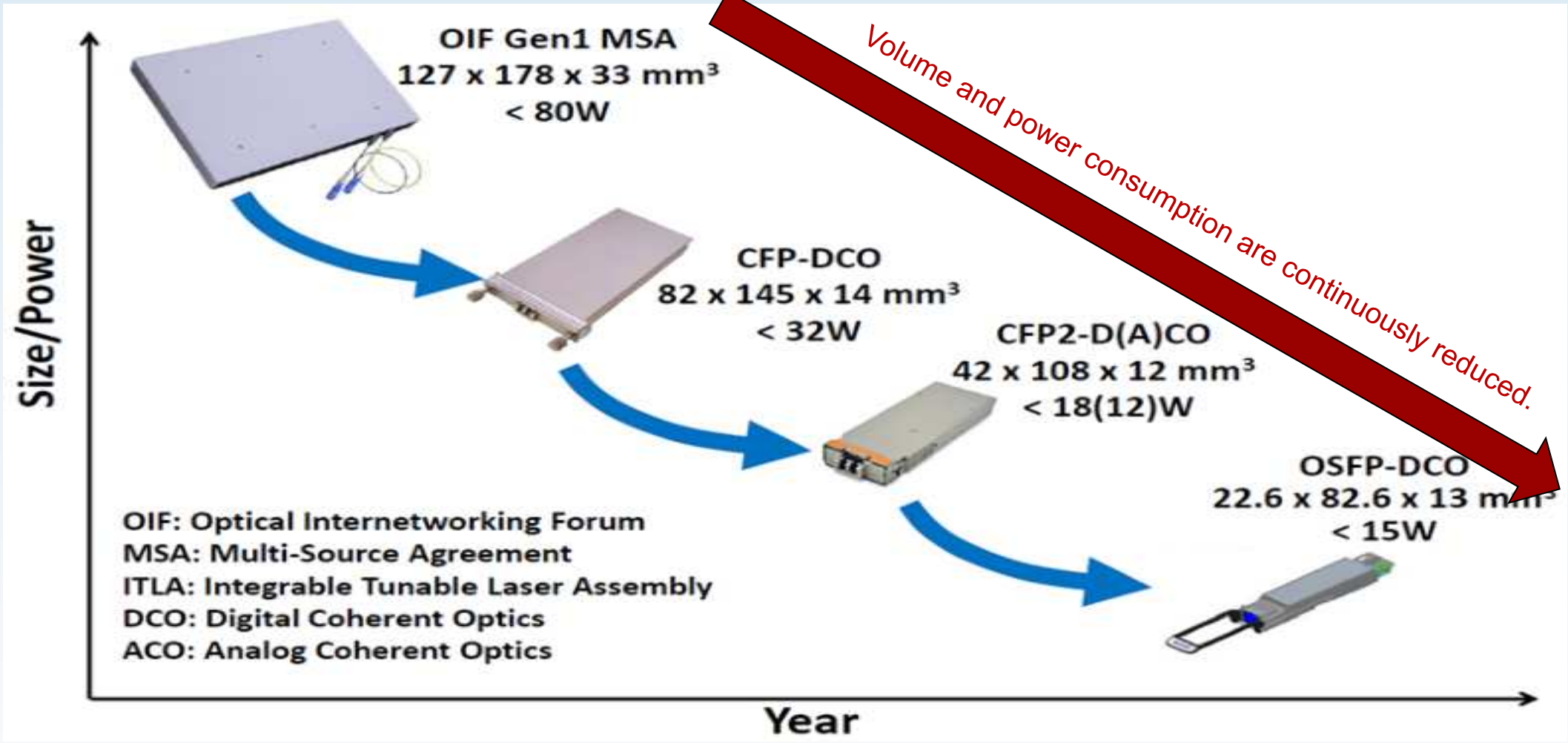
OM: optical module; REG: regenerator
OA: optical amplifier
WDM: wavelength division multiplexing

- **Large capacity: 1 wavelength x 2.5G/fiber**→80 wavelengths x 100G/fiber
- **Low cost: point-by-point electrical regeneration**→OA (without regeneration)
- **Long distance: 80 km**→2000km+

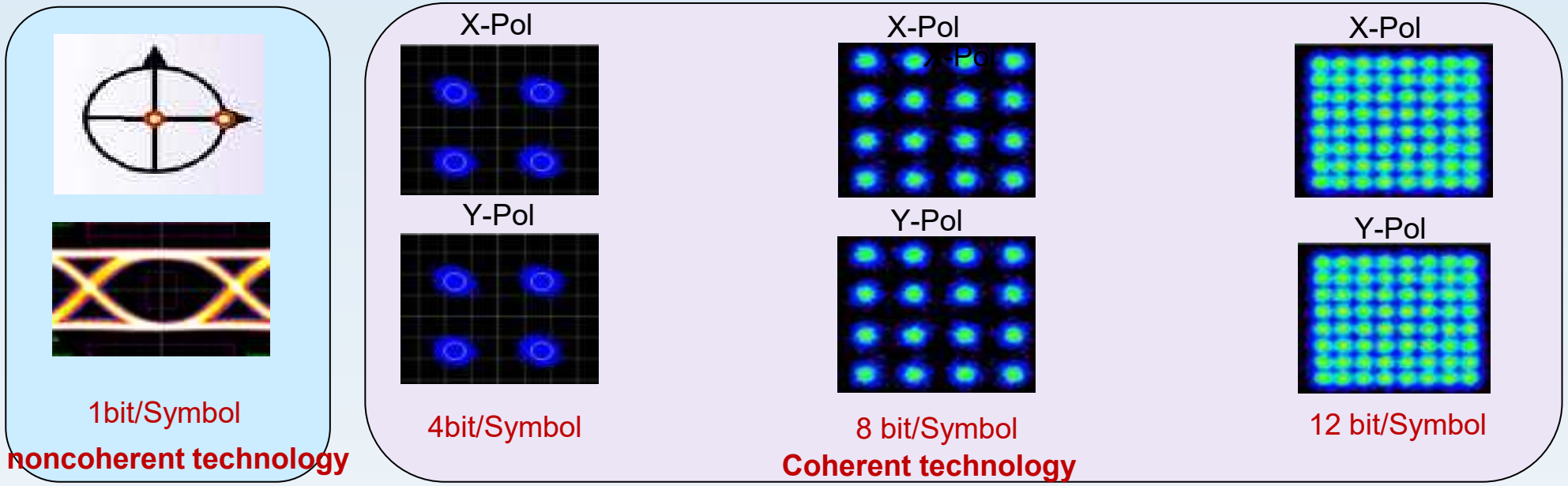
From Theory to Reality: the E2E High-Capacity Optical Communication system



Trends of Optical Modules: Miniaturized, Low Power and High Integration



Single-wavelength capacity：10G->100G->200G->400G->800G->1T+



Modulation format improvement

Baud rate increase

Baud Rate	spectral spacing	NRZ	QPSK	16QAM(E16QAM)	64QAM (EQAM)
10 GB	50 GHz	10G			
3XGB	50 GHz		100G	200G	
64 GB	75 GHz		200G	400G	600G
9xGB	100 GHz			600G	**800G**
11xGB	125 GHz		400G	800G	**1T**

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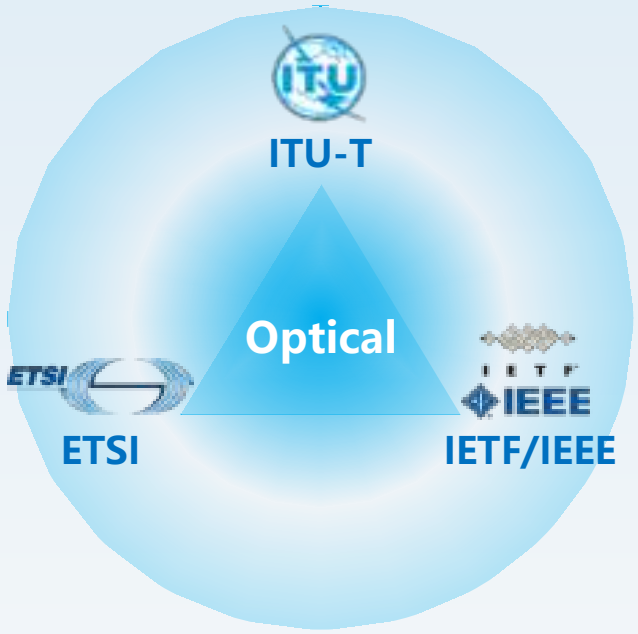
Overview of Optical Transport Standard Organization



ITU-T SG15

- Most international SDO **(100+ countries),** belongs to **United Nations**
- **Optical** (Q5/Q6): 400G/800G, C+L, fiber, OXC..
- **Electrical** (Q11): OTN/fgOTN, frame structure，clock…
- **Mgmt&Ctrl:** (Q14): ASON, Transport SDN …

ETSI ISG F5G

- Located in Europe, influence to world (60+ countries), 3GPP
- **Generations definition** of fixed network (F5G→ F5GA)
- STD development: Use cases, E2E architecture, Test spec., …
- PoCs & White papers: All-optical green network, F5G, F5GA..

IETF / IEEE

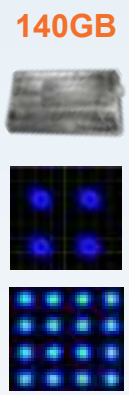
- IETF: Mgmt&Ctrl interfaces and protocols (ASON/GMPLS, Transport SDN / ACTN)
- IEEE: Transport client signal (100GE/200GE/400GE/800GE/…)

400G/800G port: Standards & Technologies Ready, Mainstream for Next 3~5 Years

400G/800G is mature and massively deployed

- Flexible rate, flexible format, flexible distance

	Format	Distance
400G	QPSK	2000km+
800G	16QAM	~600km

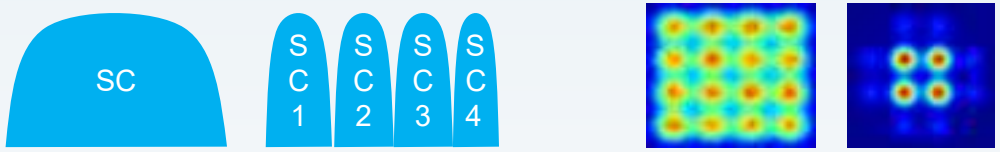


- Leading operators (Telefonica, China Mobile…) have massively deployed 400G/800G modules [>10,000/years]

1.6T is in early stage and under discussion

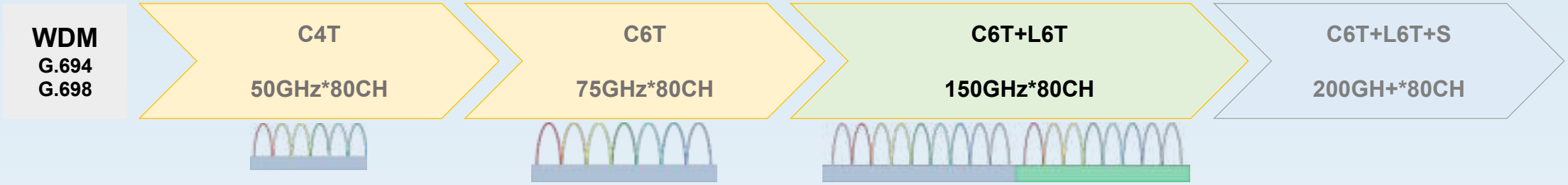
- ITU-T standard just kicked off, ready time will be ~2027
- Many technical discussions are going on

① Single Carrier Multi-carriers ② Uniformed PCS



③ Baud rate: 234GB 248GB 260GB

C6T+L6T: A Realistic Way to Increase the Fiber Capacity

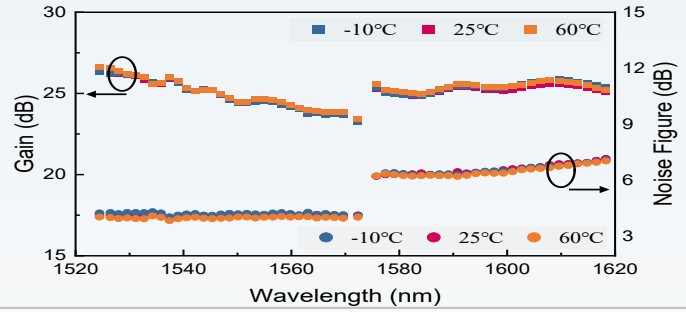


Standard contributions of C6T+L6T

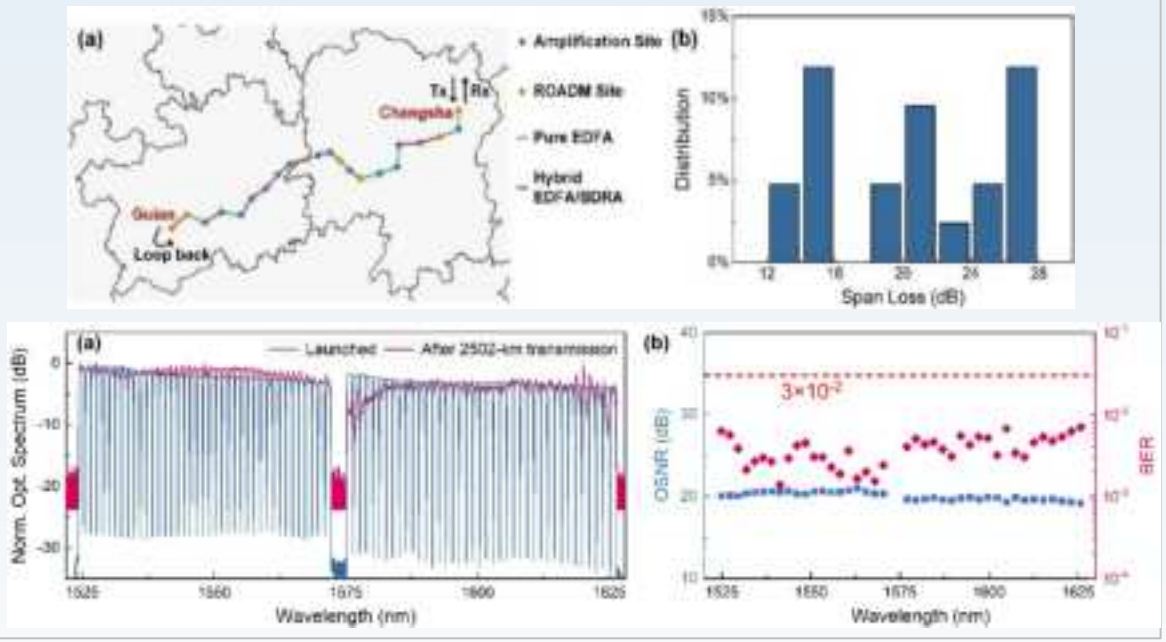
- The range definition of spectra C6T+L6T

	wavelength （nm）	frequency （THz）
C band	1524.30~1572.27	190.675~196.675
L band	1575.16~1626.43	184.325~190.325

- Gain and Noise figure of C6T+L6T EDFA



Successful filed trial of 400G LH&C6T+L6T

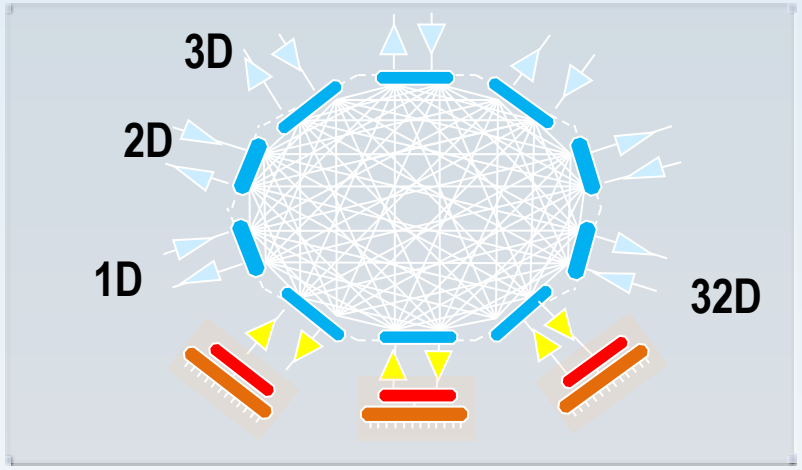


ITU-T SG15：T22-SG15-C-0834!!MSW-E Considerations of wavelength range of B400G DWDM applications

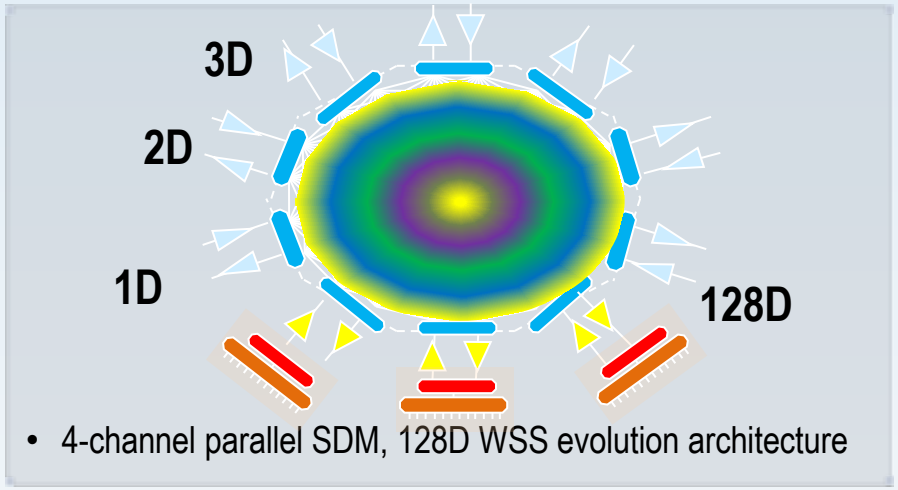
Photonic Switching Evolution: Compact System of 32D to 128D+ OXC

Optical Swtich	FOADM	ROADM	OXC Gen1	OXC Gen2
	50GHz*80CH	Flex grid	32D	64/128D

32D OXC



4-channel SDM to 128D OXC



- 4-channel parallel SDM, 128D WSS evolution architecture

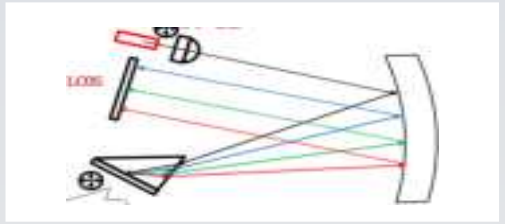
Improve Switching Speed & Isolation Performance

Super surface LCOS structure

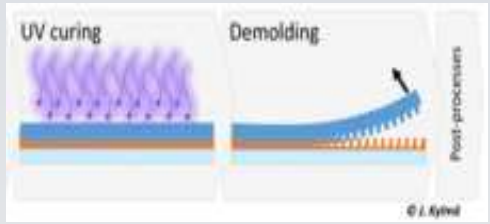
Freeform grating, reducing crosstalk

PDL-independent & High WSS integration

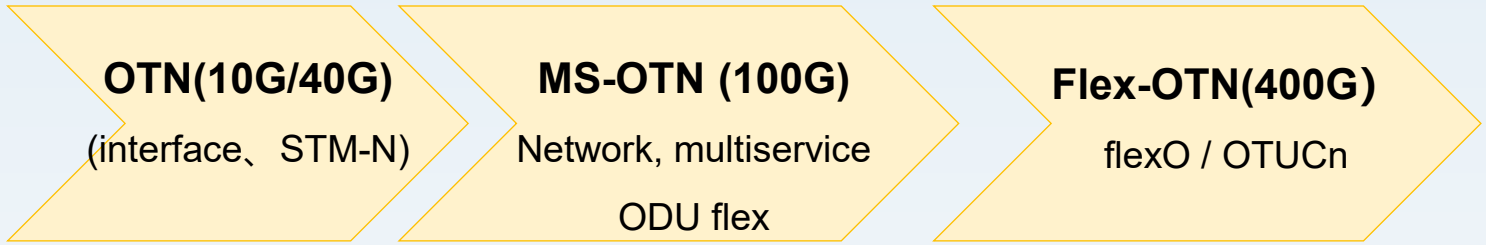
Optical path of PDL independent WSS



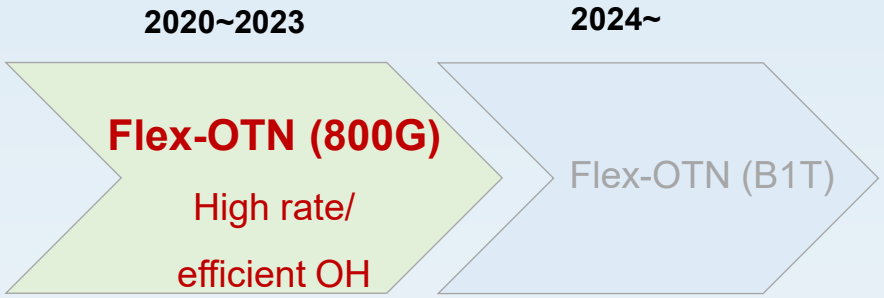
Polymer grating, Imprinting process



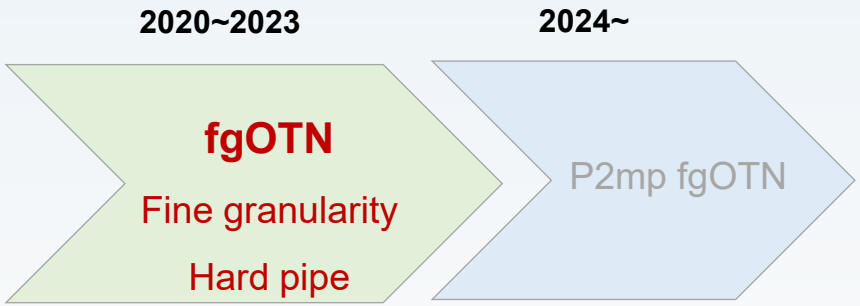
Evolution of OTN toward Higher Rate and More Flexibility



Higher Rate

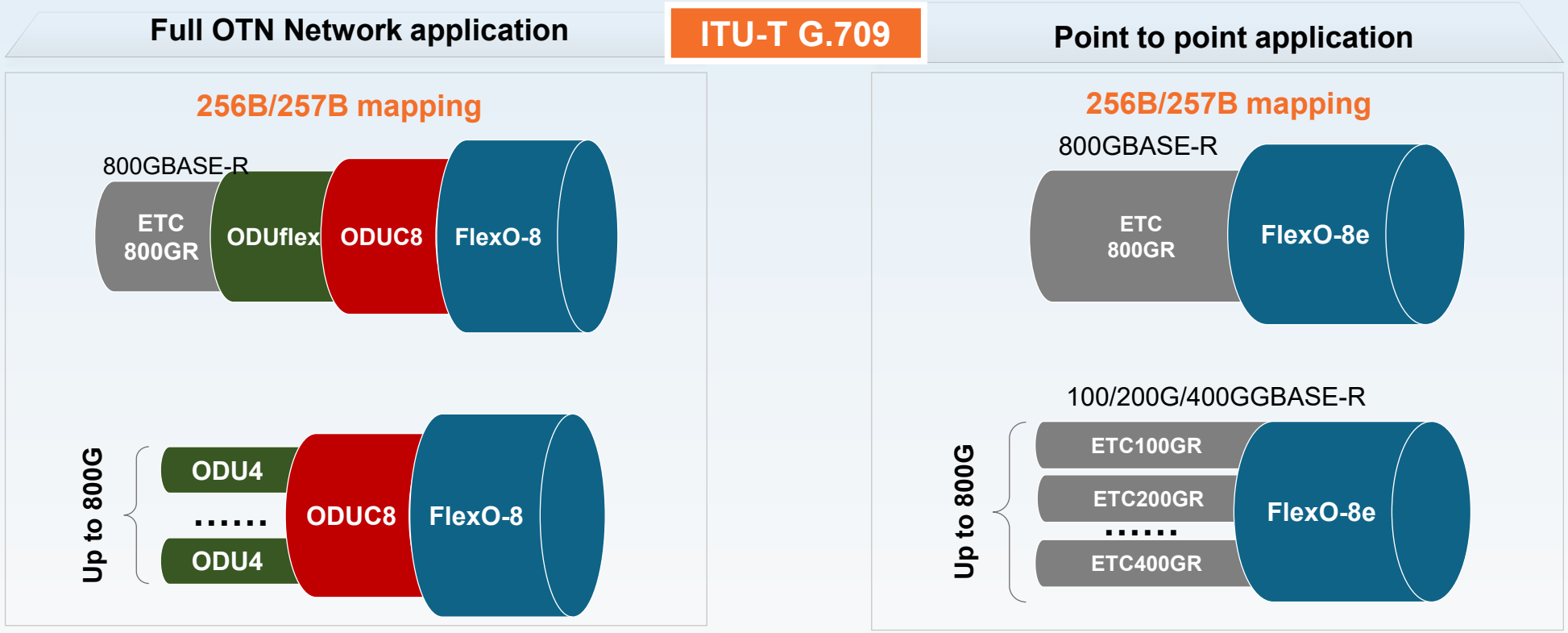


More Flexibility



OTN: Evolution to Higher Data Rate (800G) and More Efficient (0.4% OH)

- Definition of FlexO with **high data rate 800G** physical interface (FlexO-8/FlexO-8e), supporting network & P2P applications;
- Ethernet optimized 800G interface **(64B/66B with 3.125% Overhead → 256B/257B with 0.4% Overhead)**
- The format can be 400G QPSK for long reach and 800G 16QAM for metro/DCI application

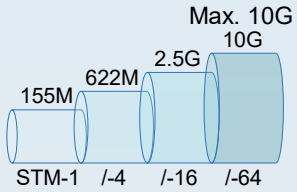


FgOTN (fine-grain OTN) : Evolution of OTN&SDH with Better Performance

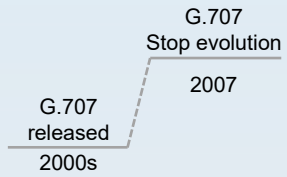
limitations of SDH&OTN

SDH

Bandwidth Limitation



No Evolution Capability



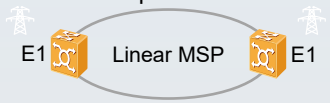
OTN

Lack of Flexibility

Mbps-level clients can't be directly transmitted by ODU0

Service Protection

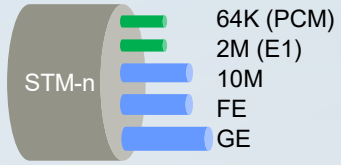
OTN mainly uses 1+1 protection



fgOTN Standard Defined by ITU-T

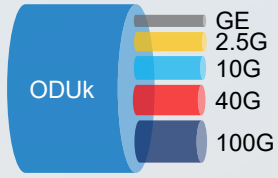
SDH

- Hard pipe
- Max 10G
- 2M~1G fine granularity



OTN

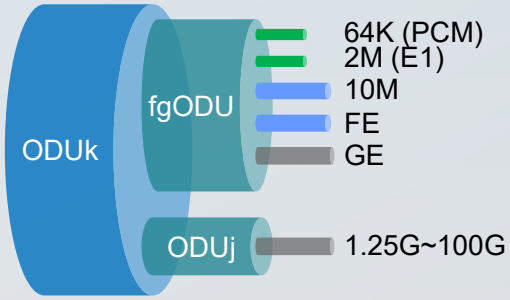
- Hard pipe
- Large bandwidth
- ≥ 1.25G container



ITU-T G.709, G.709.20

- Hard pipe
- 10M ~ 1G fine granularity
- Large bandwidth with OTN
- CBR services (teleprotection, train control, etc.)

fgOTN

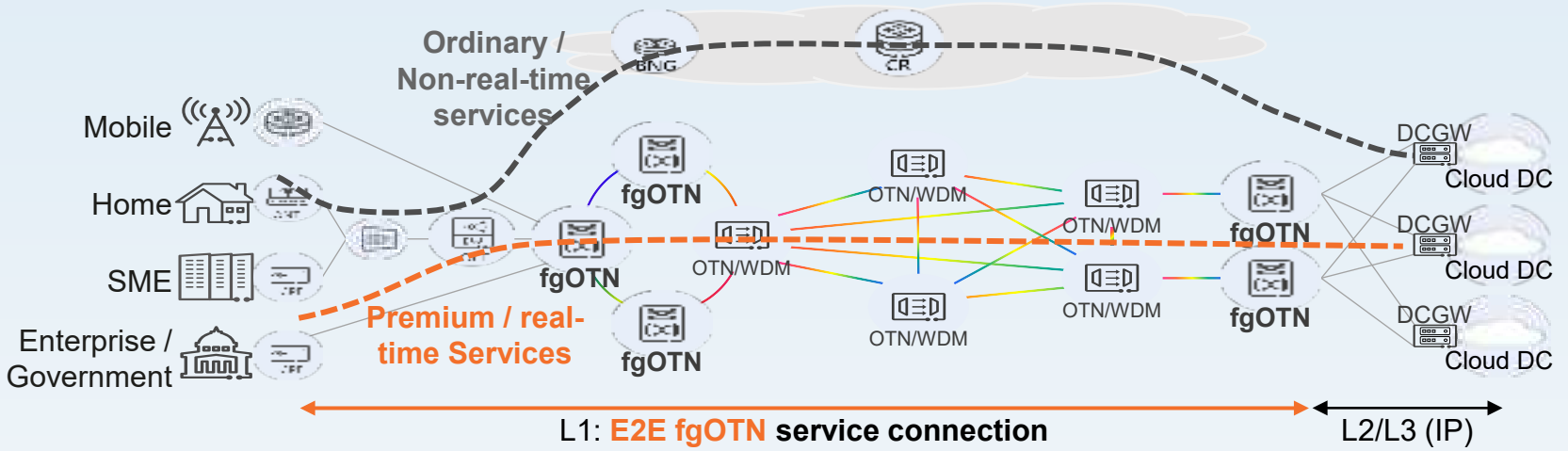


- fgOTN: organic integration of OTN&SDH, combing both advantages
- **TDM-based** hard pipe with **fine-grained** and **flexible** bandwidth from 10Mbit to 100Gbit/s
- With these features, fgOTN can be used in power grid, transportation and other high-value scenarios

ASON Control Plan: Evolution From Connection-Oriented to Service-Oriented

SOON (Service-Oriented Optical Network) Architecture

- **Service differentiation** (High-Value service)
- **Deterministic latency** (0.2~2s level→ 50ms)
- **Massive connections** (K→100K)



Related Standards

Fundamental tech. std.
- OTN (fgOTN)
- SOON concept

UC & arch. std.
ISG F5G
- Use Cases (Enterprise / home BB to multi-cloud)
- OCN (Optical Cloud Network) arch.

Protocol design
- Service control protocol
- Enhanced Connection control protocol

PoC@OFC2022
Optical service networks for Cloud VR V1 (single DC)

By: CMCC+HW+BUPT

PoC@ECOC2022
Optical service networks for Cloud VR V2 (multi-DCs)

By: CMCC+HW+BUPT

PoC@MWC2024
E2E Mgmt&Ctrl for cloud AR/VR application (NaaS)

By: CTTC+HW+ EU operator

IEEE JOCN
SOON based on fgOTN *(to be published)*

By: CMCC+HW

SDN Mgmt&Ctrl: ACTN Evolution from Automation to Autonomy

2014 ~ **Network Control**

Control ACTN

- Topology Collection
- Tunnel Creation
- Service Provisioning

Very mature

2020 ~ **Mgmt&Ctrl Integration**

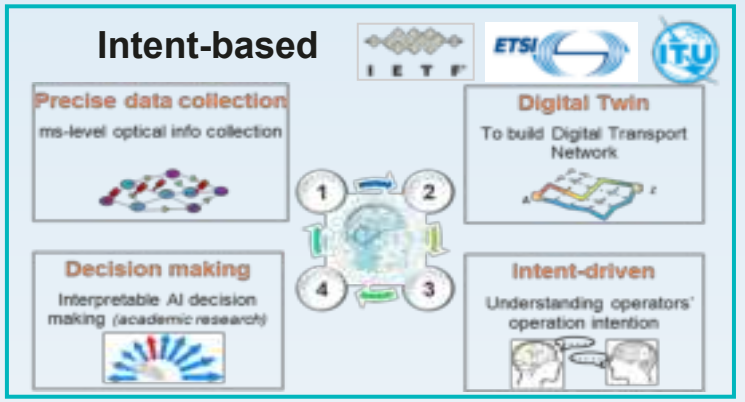
Management ACTN

- Inventory Collection
- Alarm Report
- Performance Monitoring

Control

Become stable

2024 ~ **Intelligent Mgmt&Ctrl**



Management

Control

Standard research, hot topics

Network Automation ⟷ **Network Autonomy**

- ACTN (Abstration. and Ctrl of TE Networks) has a good ecosystem, many player actively participate in it.

Key SDO Players

Optical vendors:	Huawei	Nokia	Ciena			
IP vendors:			Cisco	Juniper	Volta Networks	
Operators:	Vodafone	Telefonica	Orange	China Unicom	China Mobile	KT / SKT / …
Research:	ETRI	CAICT	CTTC	Universities		

- Many SDOs and research groups are researching on the intelligent Mgmt&Ctrl.

Summaries

- Thanks for the pioneers' works of lasers, fiber, EDFA, WDM…, optical fiber communications had played an important role in the digital world and will be the corner stone in AI era.
- ITU-T, ETSI, IETF are main SDOs for optical transport, especially ITU-T SG15 define a lot important standards（fiber, WDM, OTN, M&C）