Optical Fiber Attributes

What Matters As Capacity Demands Increase And Networks Evolve

Ian Davis

Regional Marketing Manager, EMEA and
Strategic Alliances Manager

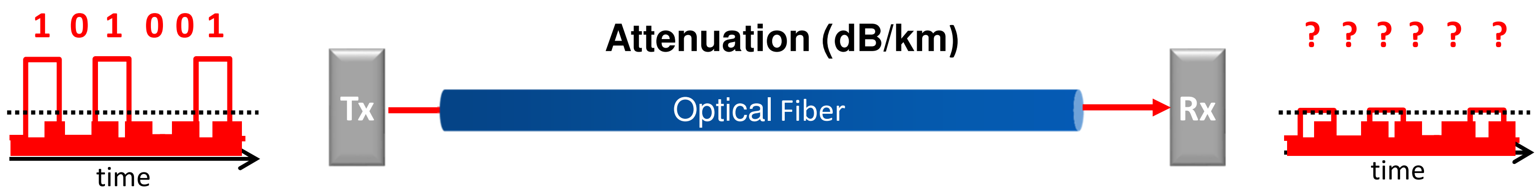
Agenda

- What attributes matter in long-haul, backbone networks?
  - At lower, conventional data rates
  - At higher, emerging data rates
- What attributes matter in access networks?
- Some emerging technologies to address capacity demand
  - Larger effective area fibers
  - Few-moded and Multi-core fibers
  - 400Gb/s transmission
- Conclusions

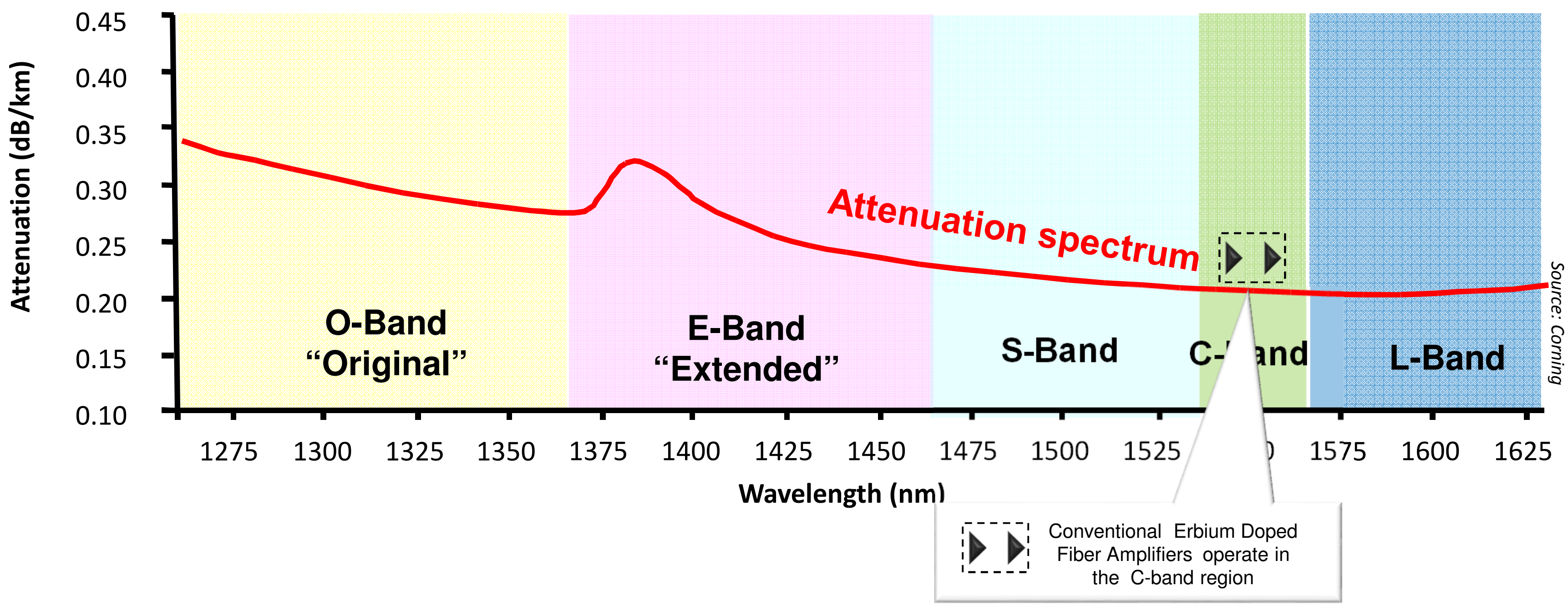
Attenuation

Key Optical Fiber Parameters in Single-Mode Fibers

- Attenuation is the weakening of the strength of an optical signal as it travels down the length of a fiber

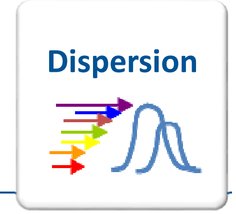


- Fiber attenuation varies across the spectrum; transmission windows are allocated at different wavelengths

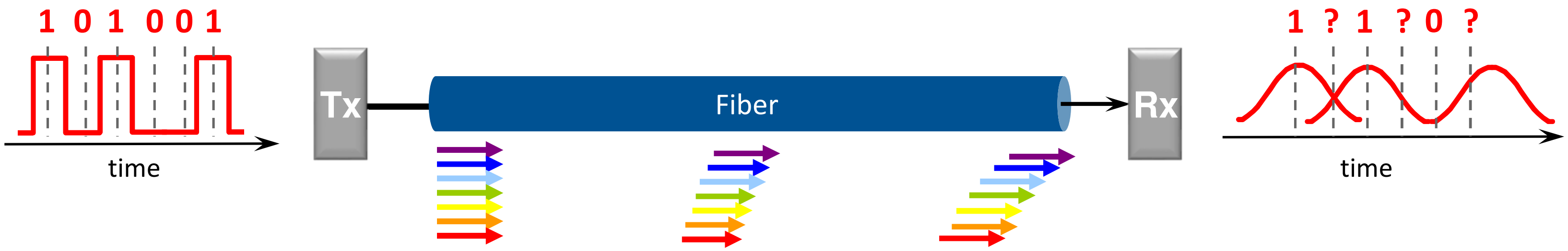


Chromatic Dispersion

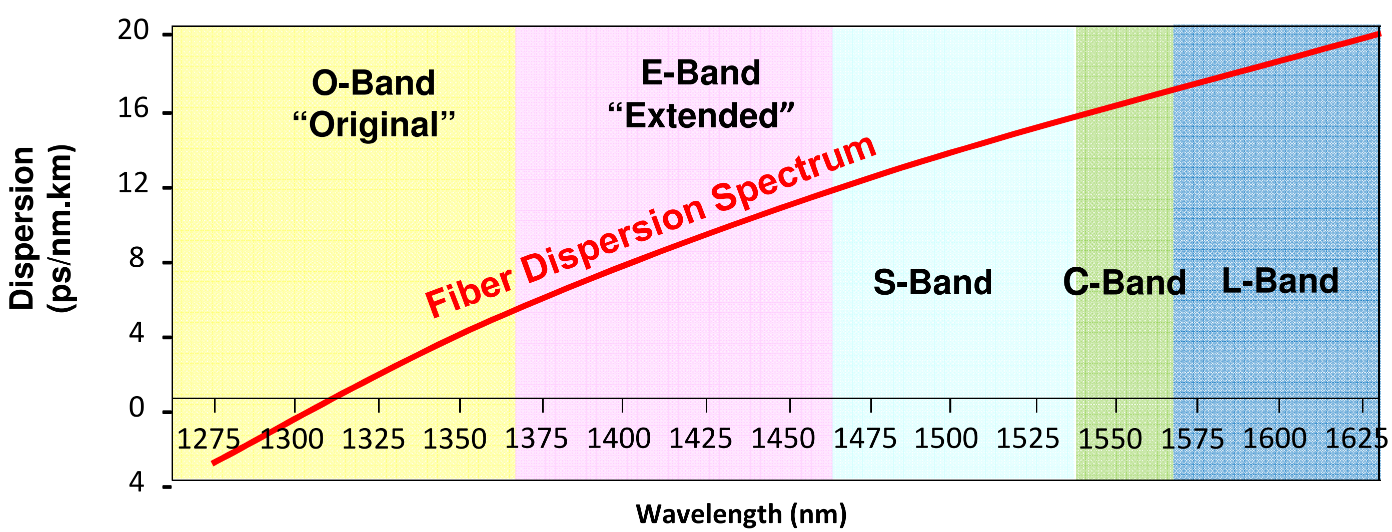
Key Optical Fiber Parameters in Single-Mode Fibers



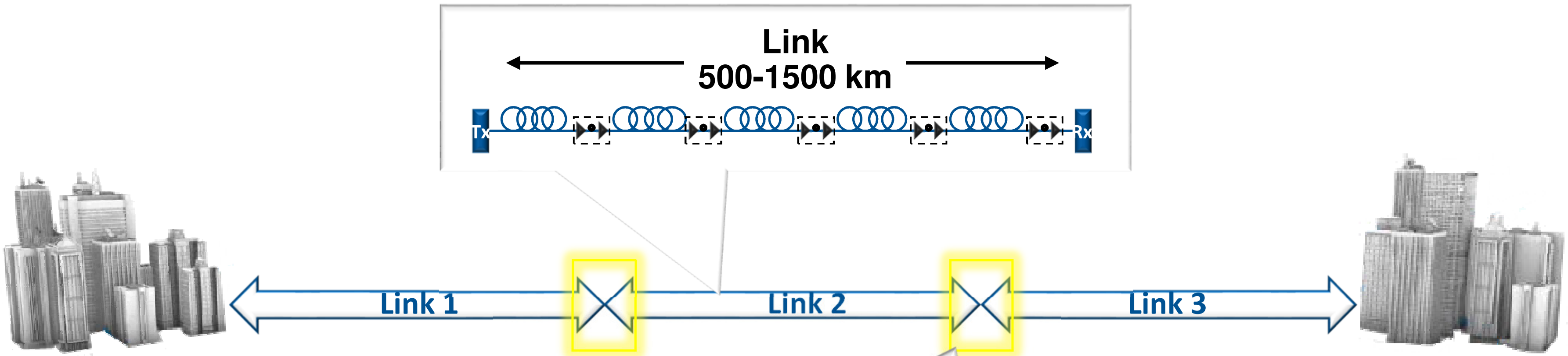
- Chromatic Dispersion is caused because different frequencies of light propagate at different speeds causing broadening of the pulse of light; in optical networking it results in signal degradation



- **Chromatic Dispersion is measured in ps/(nm x km)**

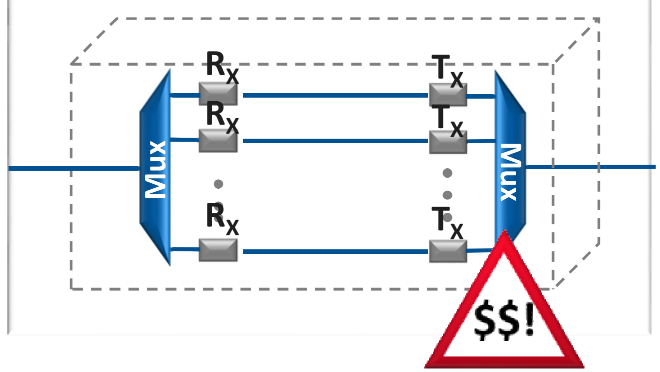


Typical Design of Long-Haul Wavelength Division Multiplexed (DWDM) Transmission Systems

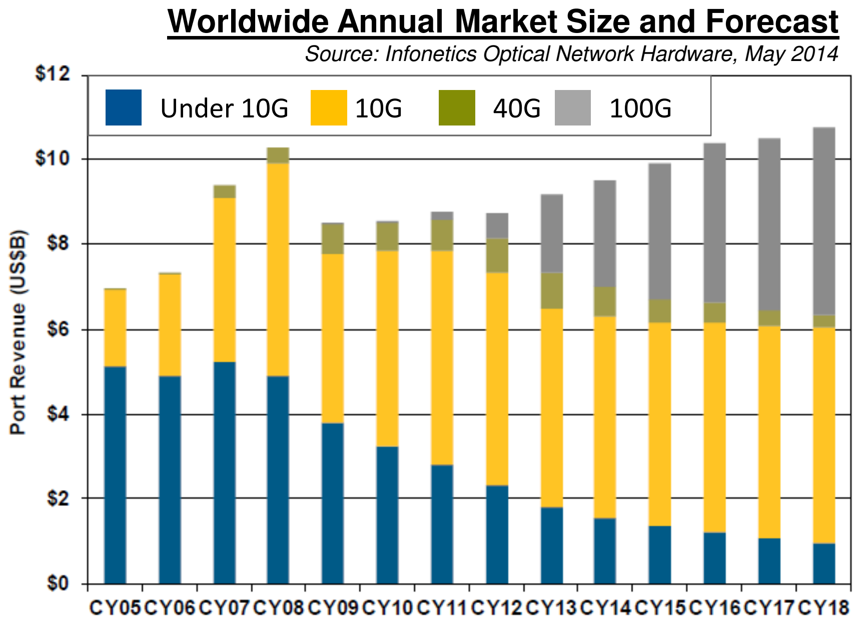


Regenerator Sites

At the end of the optical link the signal needs to be transformed to electrical and back to optical again to recover it completely before the next link



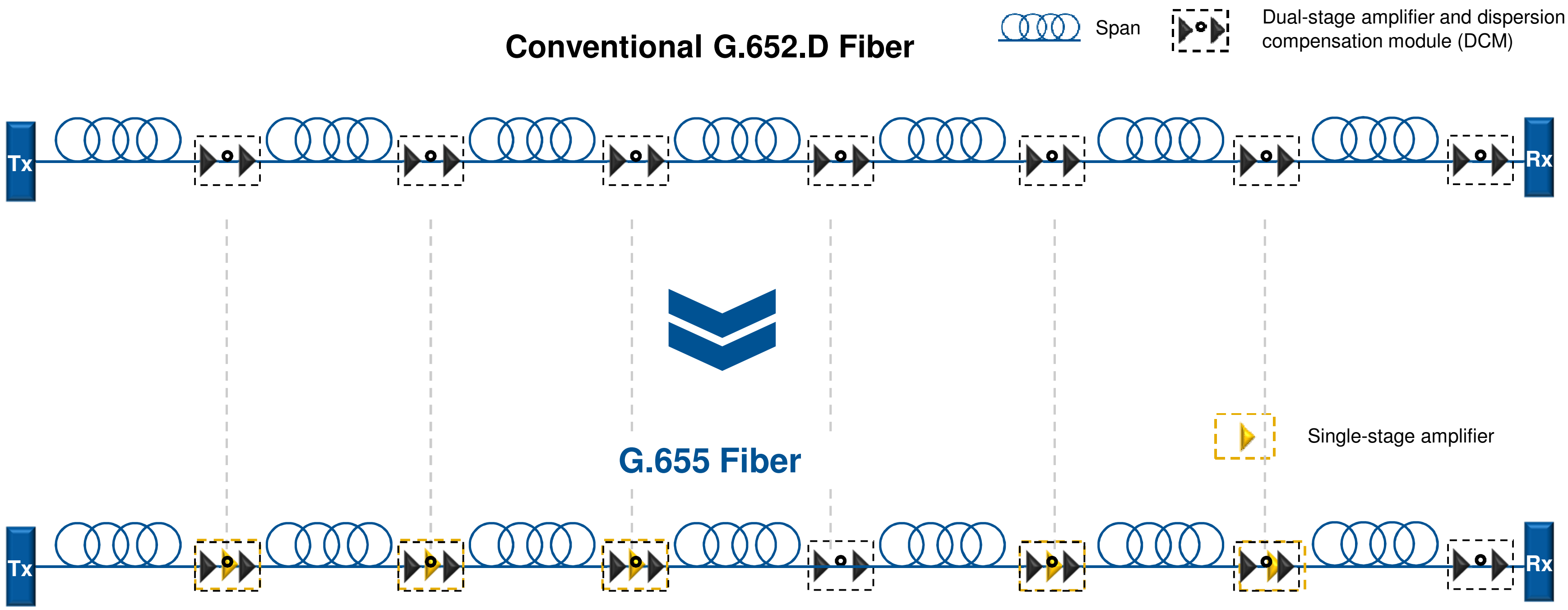
What Matters In Long-Haul At Lower Data Rates?



- The industry trend is towards the adoption of higher data rates with 100G (generally coherent detection) systems gaining in popularity but 10G systems remain as the predominant data rate for many networks
- 10G & 40G systems generally use direct-detection (or non-coherent detection) systems which are less expensive but are dispersion limited

Low dispersion fibers (e.g. G.655 non-zero dispersion shifter fiber) offer benefit in lower data-rate systems at 10G & 40G

G.655 Fiber has low dispersion in the C-band
Enabling equipment reduction and savings

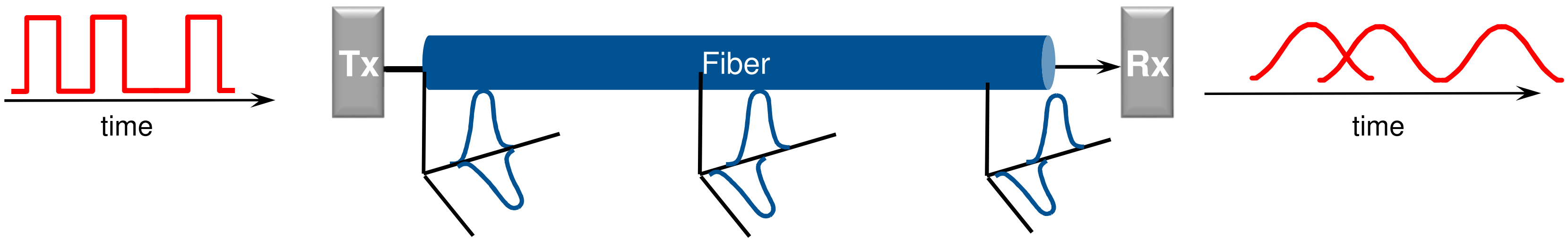


DCMs eliminated, enabling the use of simpler, lower-cost single-stage EDFAs

Low dispersion fibers enable the use of single-stage amplifiers reducing the equipment needed in the system and lowering CapEx and OpEx costs

Polarization Mode Dispersion (PMD)

- Polarization Mode Dispersion is caused by internal stresses in the core of the fiber that change the refractive index making one polarization of light propagate faster than the other
- This causes distortion of the pulse of light resulting in signal degradation

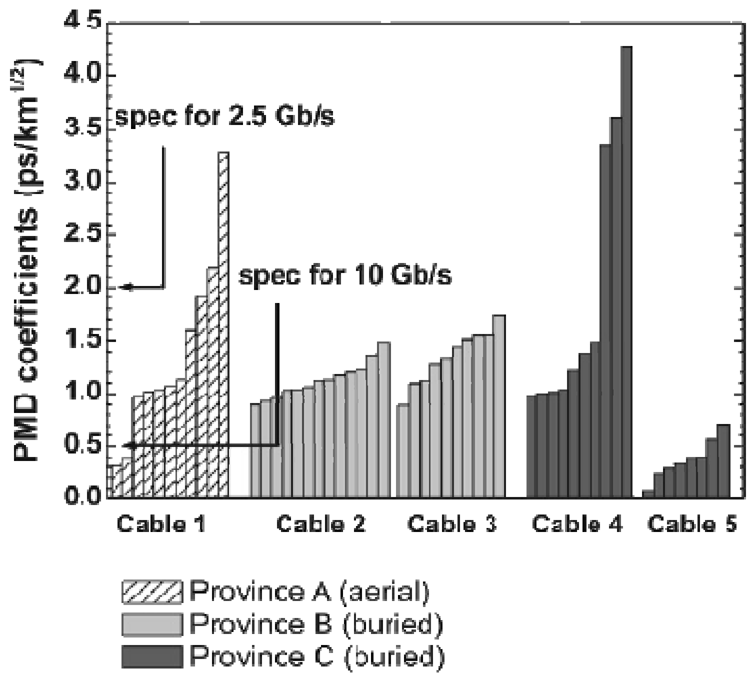


- Older installed fiber is particularly susceptible
  - Some operators have found that legacy links were incapable of desired upgrades

Line Rate	PMDMax (10% of bit period)
2.5 Gb/s	40 ps
10 Gb/s	10 ps
40 Gb/s	2.5 ps

Study of Polarization Mode Dispersion*

"…field measurements made on spare fiber in the South African optical fiber network show the extent to which the network may be upgraded to higher data rates."



** Source: A.B. Conibear, A.W.R. Leitch, N.A. Sibaya, T.B. Gibbon and L. Viljoen, Department of Physics, Nelson Mandela Metropolitan University, South African Journal of Science, Vol. 101, pp. 275, 277 (2005)*

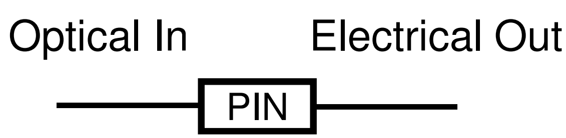
Fig. 2.PMD coefficients for individual fibers in cable 1 in Province A, cables 2 and 3 in Province B, and cables 4 and 5 in Province C.

Because of high PMD, some networks with older cables were found to be incompatible with upgrade to even moderately higher data rates

What Matters In Long-Haul At Higher Data Rates?

Coherent Detection Technology Dominates at 100Gb/s

Direct Detection

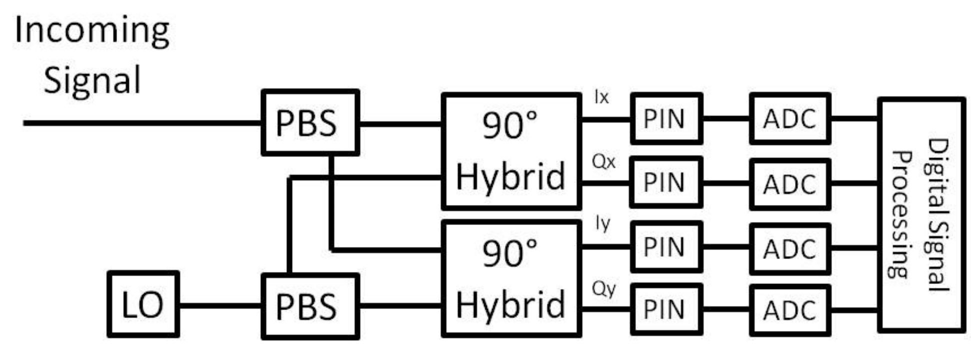


PIN: photodetector

Cheap and Simple

Detects only amplitude

Coherent Detection

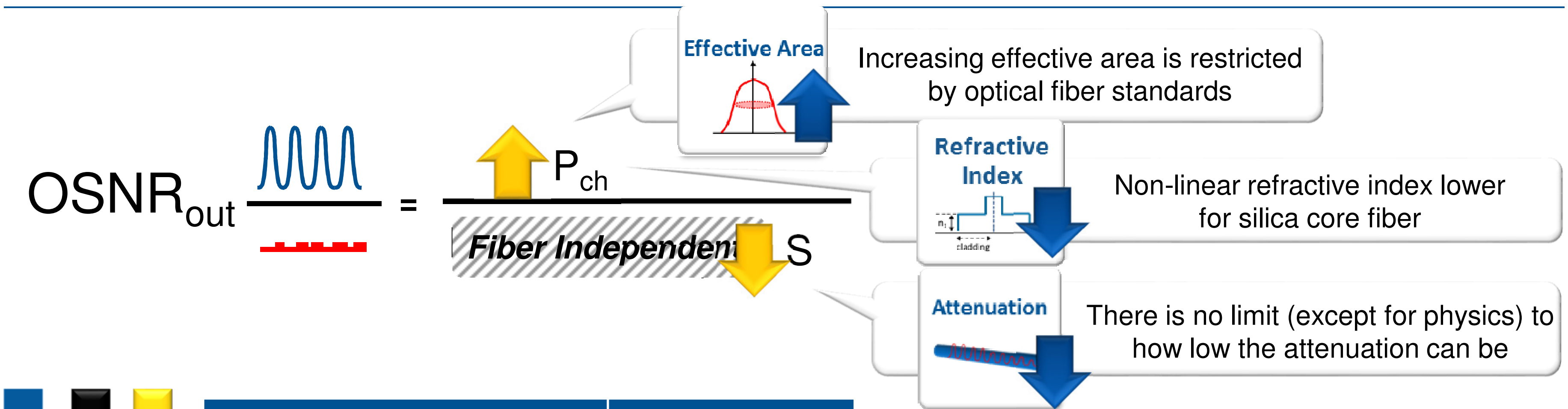


- Detects the full optical field amplitude, phase, and state of polarization
- Enables the use of more spectrally-efficient modulation formats
- **Compensation** for **chromatic dispersion** and **PMD** at the receiver

More complex and expensive than direct detection

What Matters In Long-Haul At Higher Data Rates?

The answer is Optical Signal to Noise Ratio (OSNR)



Modulation Format	Single channel data rate
PM-BPSK *2 bit per symbol*	50G
PM-QPSK *4 bits per symbol*	100G
PM-8QAM *6 bits per symbol*	150G
PM-16QAM *8 bits per symbol*	200G

** 2012, A. Carena et all, Modeling of the Impact of Nonlinear Propagation Effects in Uncompensated Optical Coherent Transmission Links", University of Turin*

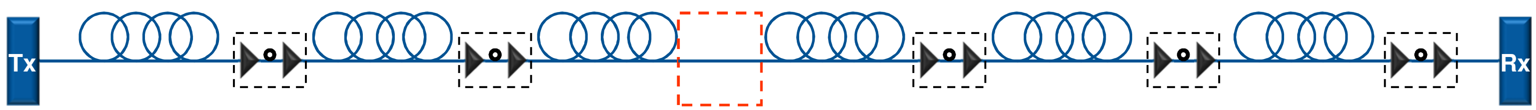
Loss Matters.

How Ultra-Low Loss Delivers Value In Long-Haul Networks

Span — Dual stage amplifier and dispersion compensation module (DCM)

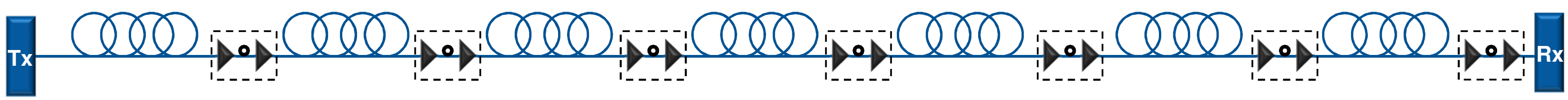
EQUIPMENT REDUCTION

Ultra Low-Loss Fiber



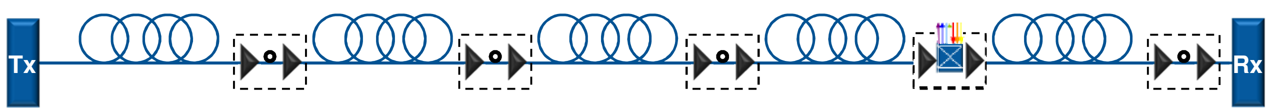
NETWORK REACH

Ultra Low-Loss Fiber



CAPACITY UTILIZATION
Optical Switching

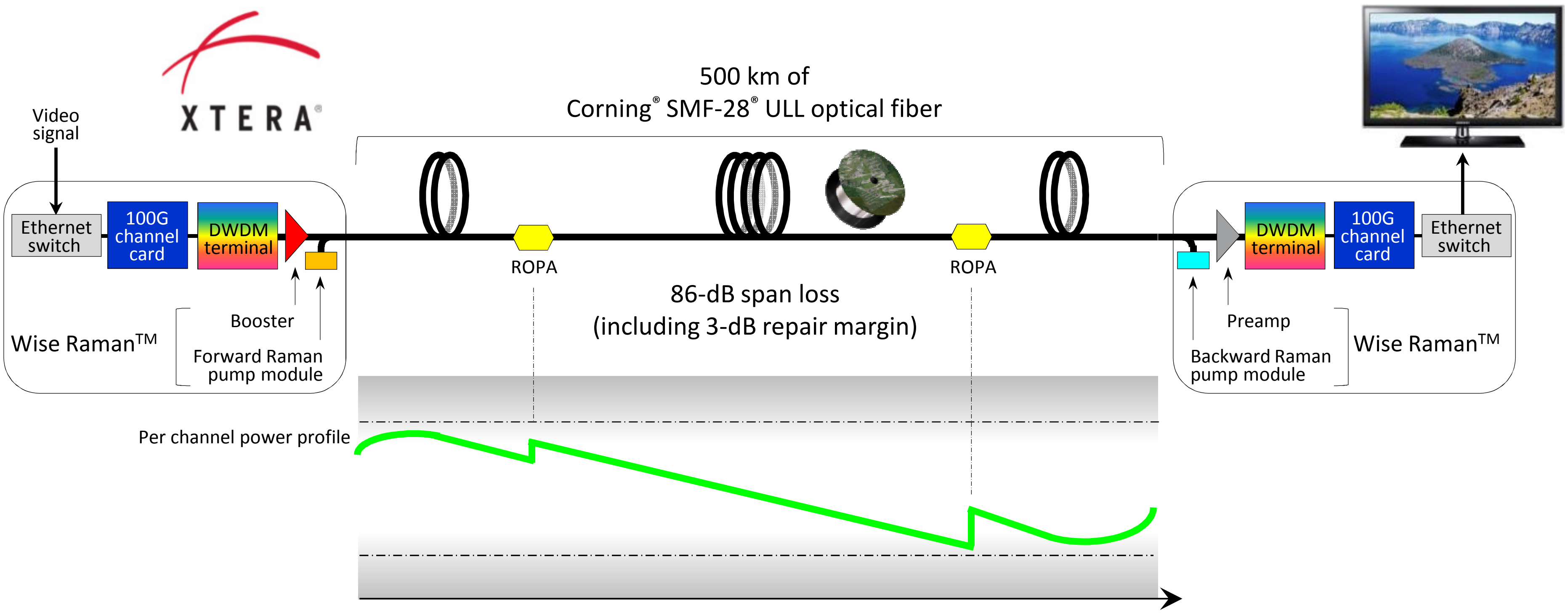
Ultra Low-Loss Fiber



Simpler system and longer reach at a lower cost.
Optical switches with minimum compromise on reach.

SMF-28® ULL Fiber Enables Longer Spans

OFC 2014 – Joint Corning & Xtera demonstration of 100G over single span of 500 km



SMF-28 ULL fiber

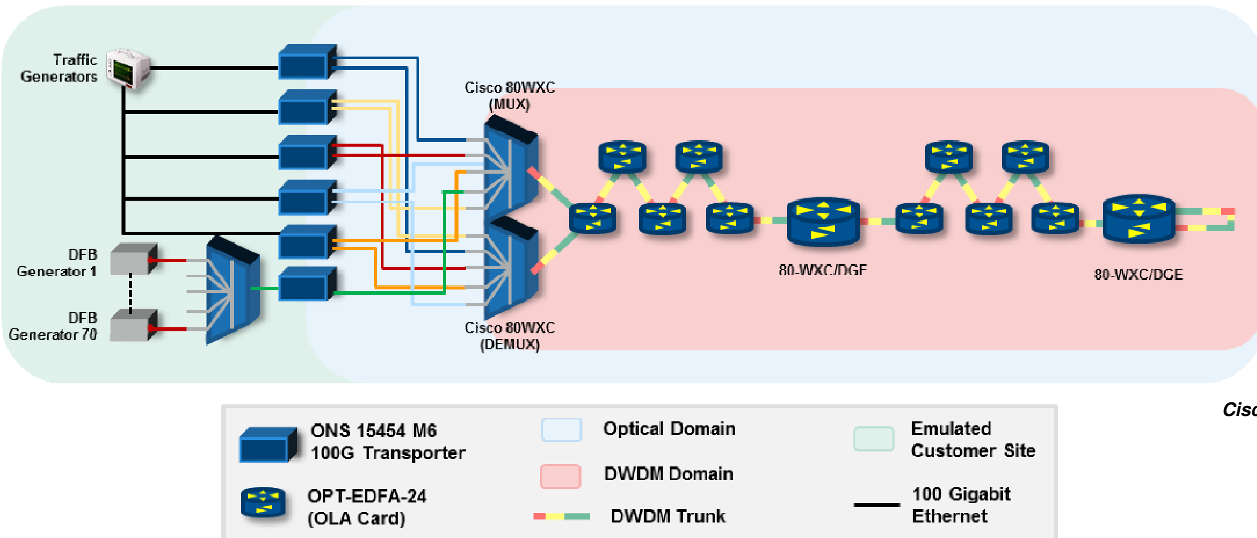
- The more demanding Optical Signal to Noise Ratio (OSNR) requirements of 100G result in significantly reduced network reach
- This technology also enables greater flexibility in the positioning of intermediate amplification sites providing operators with the possibility of more cost-efficient networks crossing remote areas

Corning® SMF-28® ULL fiber supports 500 km un-repeatered span at 100G

SMF-28® ULL Fiber Enables Longer Reach

Cisco 100G transmission over 3000km (24 x 125km spans)

Loss Matters.



Cisco® is a trademark of Cisco Systems

- 100 Gb/s DWDM system
- 75 channel Dense Wavelength Division Multiplexing (DWDM)
- EDFA amplification only
- 3,000 km un-regenerated, error-free transmission, 24 spans of 125 km each

SMF-28 ULL fiber

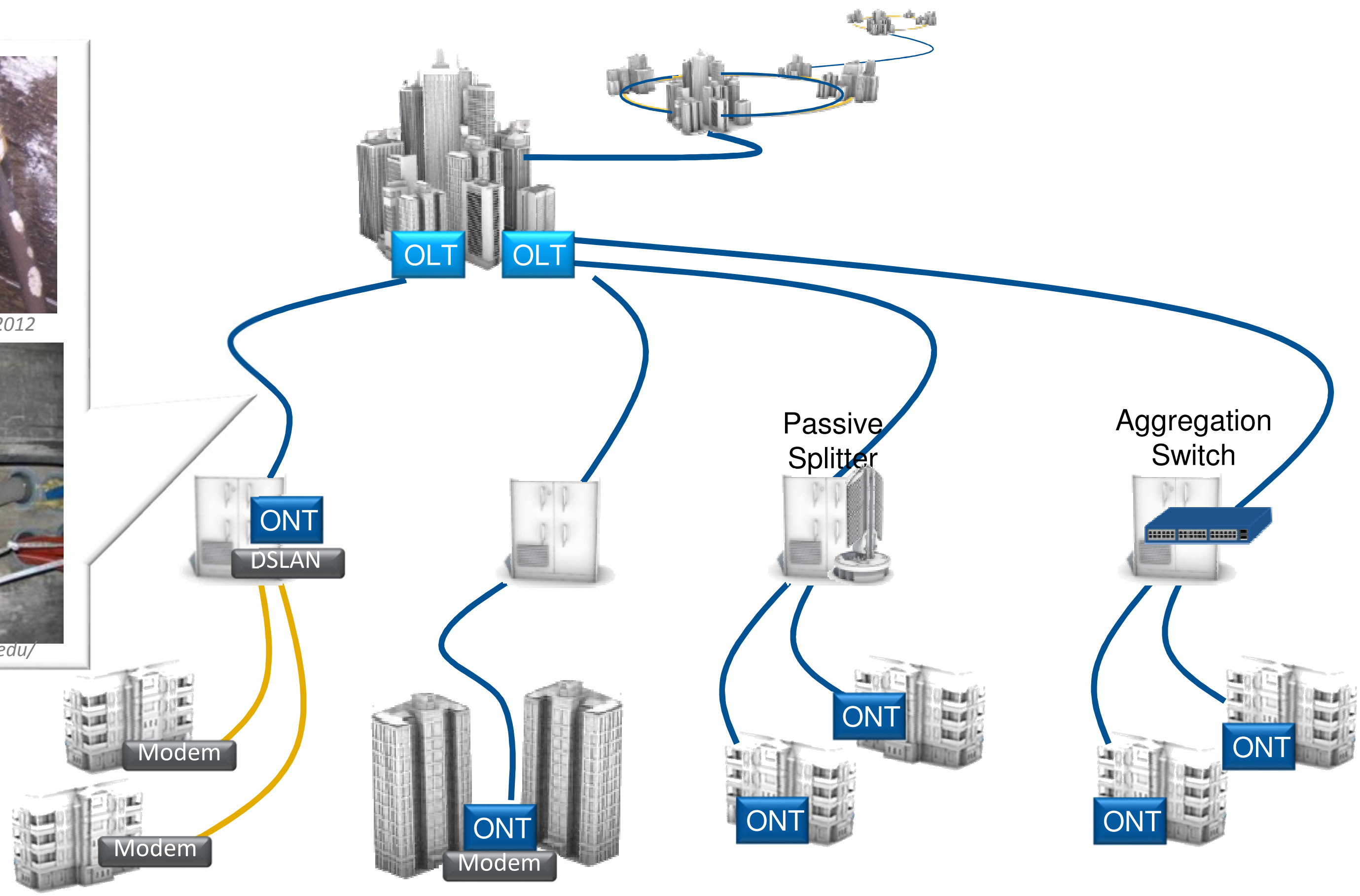
SMF-28 ULL fiber enables 35% reach improvement compared to standard single-mode fiber

What Matters When Fiber Approaches The Home?

The biggest challenges encountered are space and the speed of installation

Source: Broken Telephone, June 2012

Source: ts.unc.edu/



Very high bitrate Digital Subscriber Line (VDSL)

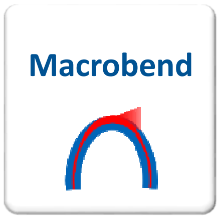
Fiber to the Building (FTTB)

Gigabit Passive Optical Network (GPON)

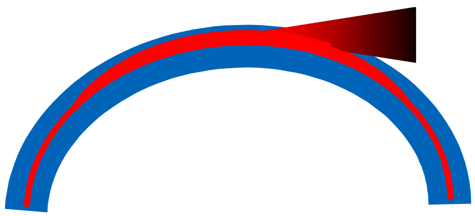
Point-to-Point (P2P)

What Matters When Fiber Approaches The Home

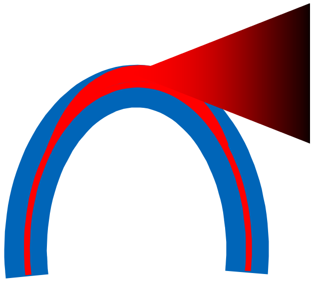
Macrobending and Microbending



- With Macrobending the optical signal leaks out of the fiber at bends reducing the signal strength



Moderate loss with moderate bends



Increased loss with tighter bends

ITU-T G.657 Standard

The Macrobend Improved Fibers

- ITU-T G.657 recommendation defines two categories of fibers:
  - **Category A**, is fully-compliant with the ITU-T G.652 single-mode fibers and can also be used in other parts of the network
  - **Category B**, is not necessarily compliant with ITU-T G.652, it is capable of low macrobending loss at very low bend radii and is pre-dominantly intended for in-building use

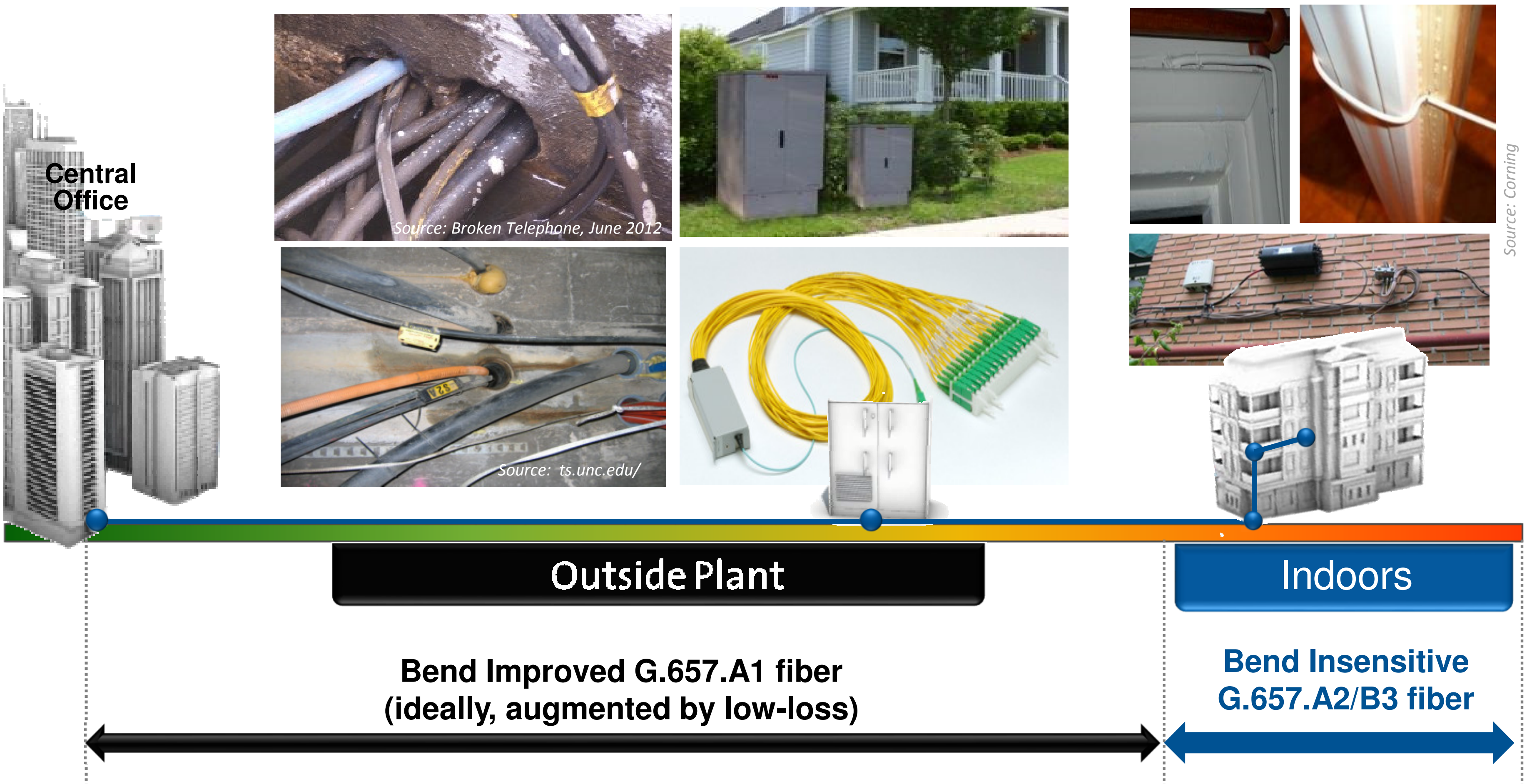
Minimum specified bend radius	ITU-T G.657 Recommendation	
	Category A (G.652 compliance required)	**Category B** (G.652 compliance not required)
	Loss per turn at minimum bend radius at 1550 nm	
10 mm	A1 ≤ 0.75 dB	
7.5 mm	A2 ≤ 0.5 dB	B2 ≤ 0.5 dB
5 mm		B3 ≤ 0.15 dB

Source: ITU-T G.657 Recommendation

- The sub-categories specify different grades of performance depending on the severity of bending in the application and the requirement for backwards compatibility

- G.657.B3 products are available that achieve ultra-low bend loss whilst maintaining compliance with G.652.D

Different Fiber Types for Different Parts of the Network



The bend improved performance of G.657.A1 fibers is sufficient for outside plant applications
More bend resistant G.657.A2 or B3 fiber necessary inside the building

Optical Cable Design Portfolio

DUCT & BURIED

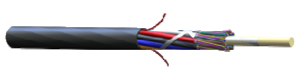
Loose Tube

- **Most common OSP cable design**, featuring stranded buffer tubes containing loose fibers.
- Installed in **ducts**
- Suitable for **LONG-HAUL** or **ACCESS** applications

Armored Loose Tube

- Loose tube design with armor for extra strength
- **Direct buried** in the ground
- Best-suited for **LONG-HAUL** applications

Minicable



- **Miniaturised** loose tube design
- Installed in **microducts**
- First used in **ACCESS**, now also found in **LONG-HAUL**

AERIAL

- More cost-effective than duct/buried deployments, as long as rights of way are available

ADSS

- All-Dielectric (metal-free) Self-Supporting
- Designed for **long aerial spans**
- Best-suited to **LONG-HAUL** applications

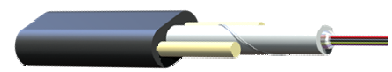
Figure-8

- Steel messenger for **easy installation** on poles
- Designed for **short aerial spans**
- Best-suited to **ACCESS** applications

DROP

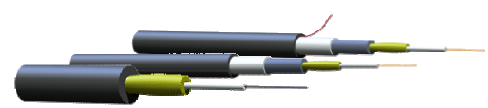
- For low-fiber count final **FTTH connections** to the customer house or Multi-Dwelling Unit (MDU)
- Recommended for use with bend-insensitive fibers

Drop Cable w/GRP Strength Members



- 1-12 fibers
- Capable of relatively **long spans**
- Robust drop cable for **aerial applications**

Rounded Drop Cables



- 1 fiber only
- Best-suited to **short aerial spans** and **façade installations**
- Preferred drop design in EMEA

So Practically, What Happens Next?

Bandwidth needs continues to grow, driven by demand for video content

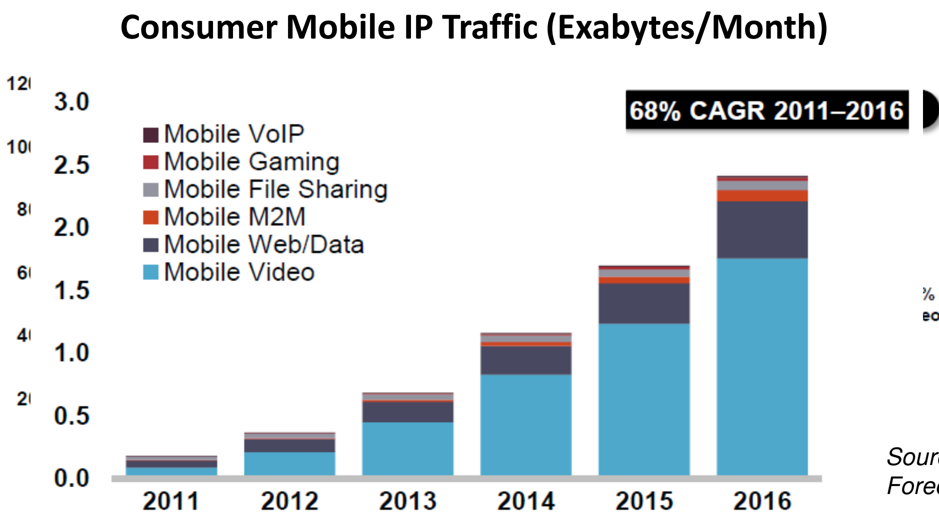
infinera

"Video, Mobility and Cloud are helping to drive around 40% annual growth in internet demand"

Source: Infinera (2012), Super-Channels DWDM Transmission at 100Gb/s and Beyond

CISCO

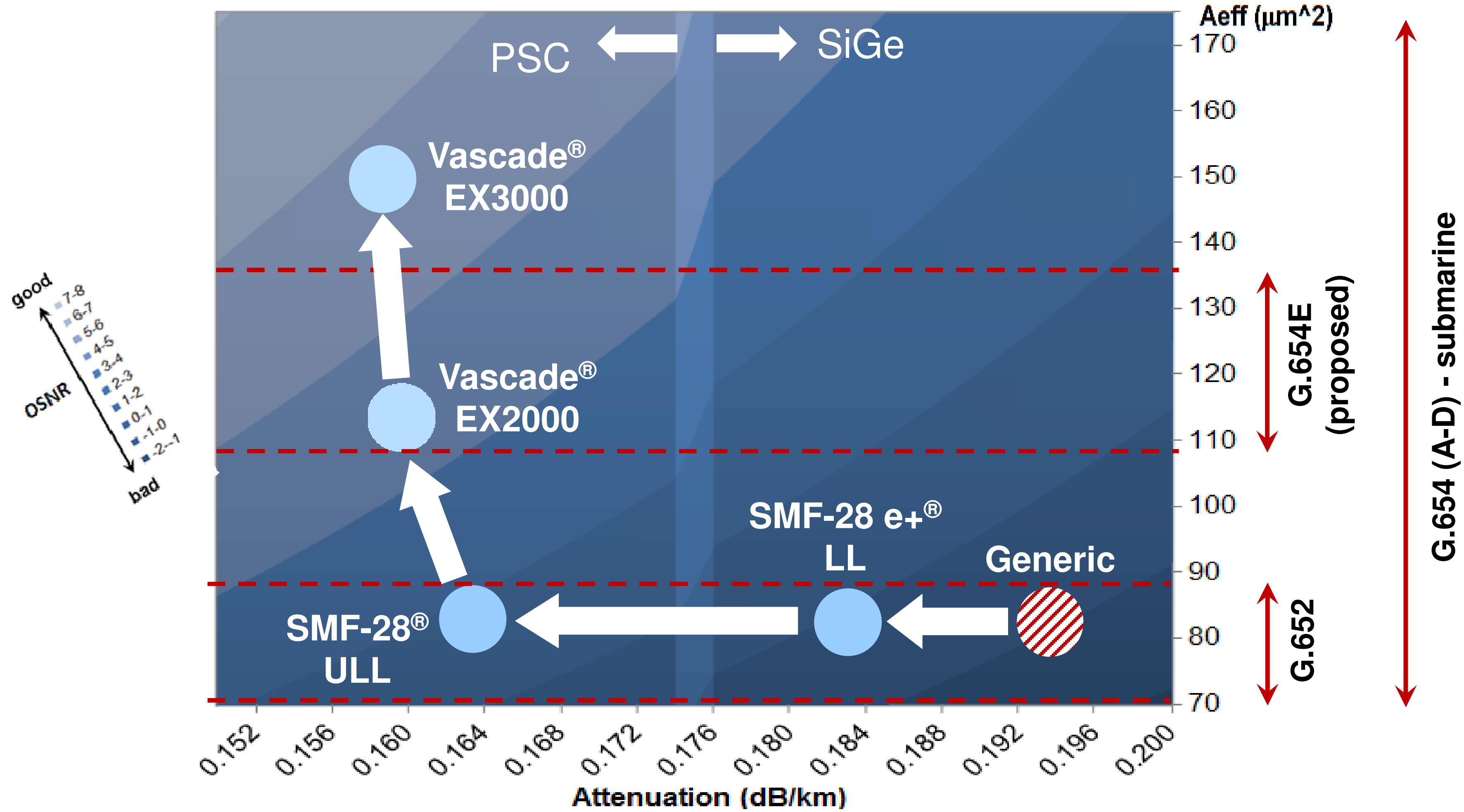
*"By 2018, there will be nearly **4 billion** global Internet users (more than 51% of the world's population), up from 2.5 billion in 2013"*



Source: CISCO VNI Global Forecast, 2011-2016

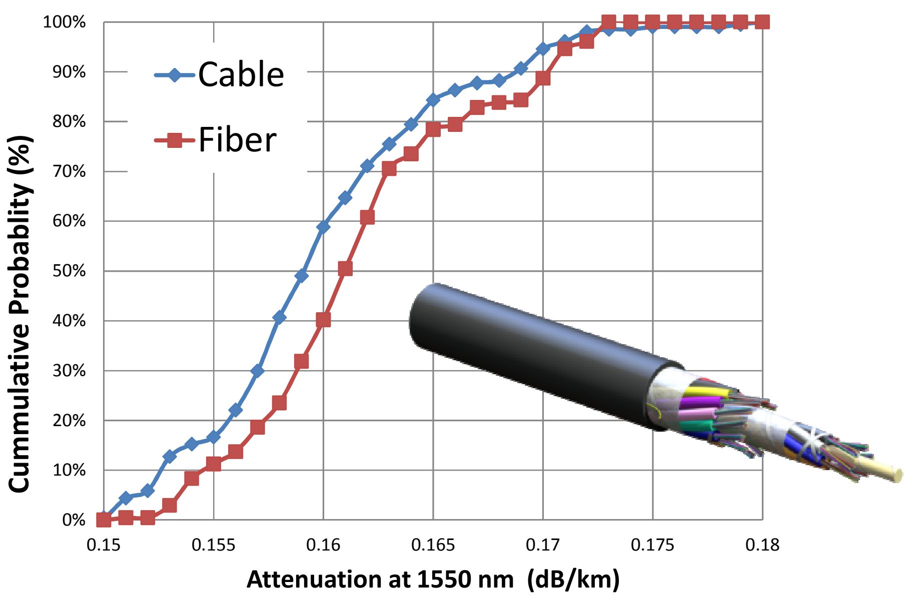
Recall, increasing capacity with acceptable reach demands improved OSNR

May require the development of new terrestrial fiber designs



A new terrestrial standard (G654.E) can push the range of Aeff to 110 – 135µm^2
but considerations related to bend performance need to be taken into account

Corning has demonstrated that Vascade® EX2000 can be cabled in terrestrial cable



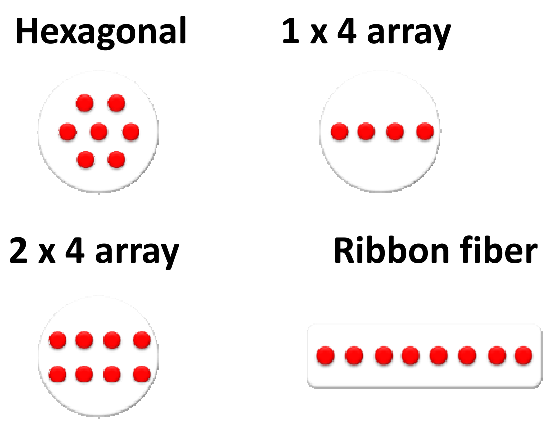
- Cable: 8.3 km Altos loose tube 204 cable on a 0.9m diameter spool
- Optical Fiber: **Vascade EX2000** (total 1668 km) with A_{eff}=112 μm^2
  - Median attenuation improved to 0.159 dB/km in cable, max attenuation 0.173 dB/km
- Span: **556.7** km, total loss **90.2** dB, spliced attenuation **0.162 dB/km**

With Larger Effective Area Even Longer Reaches Can Be Achieved

- World record for fiber attenuation at 1550 nm 0.149 dB/km with A_{eff} = 135µm^2
- This fiber will significantly increase the reach of 100G trans-oceanic networks
- 112 Gb/s over record 7,200km for a 100km spaced EDFA-only system (Downie et al OFC ’11)

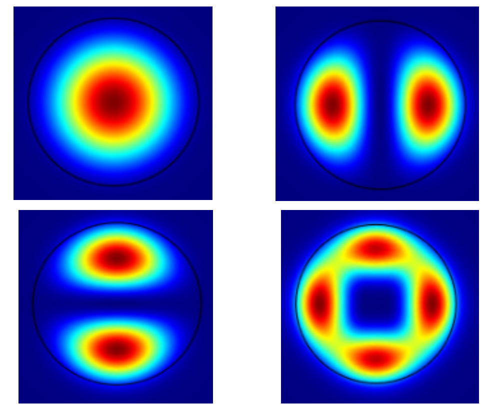
Some Emerging Fiber Designs For Increased Capacity

Multi-core Fibers



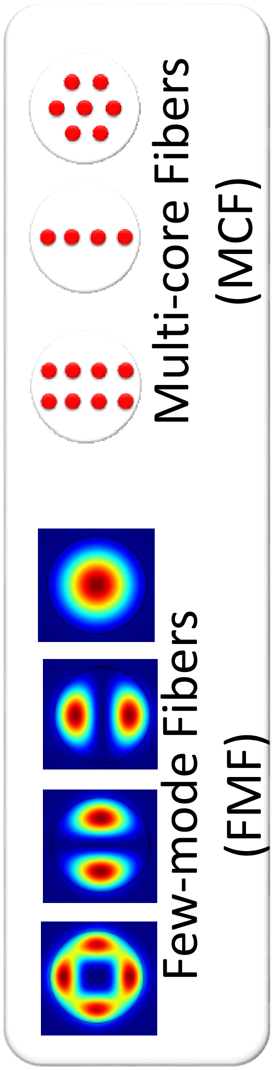
- Hexagonal structure has higher packing density
- Linear arrays are compatible with linear transceiver arrays
- Round fiber: Number of cores is limited by the cladding diameter
- Ribbon fiber: Number of cores can be scaled in one dimension and offers potential lower crosstalk

Few-mode Fibers



- Increase the core size to enable transmission on more than one mode
- Information can be carried on both fundamental and higher-order modes

But The Emerging Fiber Developments Have Significant Challenges to Practical Use



- Crosstalk between different cores (MCF) and different modes (FMF)
- Creation of low cost manufacturing processes
- Manufacturing MUX/DEMUX and amplifiers for MCF and FMF on a production scale
- Challenges for field splicing and connectorization
- Will carriers be prepared to abandon existing installation procedures and shift to FMF or MCF?
- Can you justify relatively small increase in capacity relative to SMF?

400G Has Been Developed…
… And It Is Beginning to Being Installed

System Houses

ciena. : the network specialist

Ciena Press Releases

ZTE中兴

Press Center

ZTE demonstrates single carrier 400G ultra-long transmission

2014-03-17

Successfully transmits over 3600km in standard single-mode fiber

17 March 2014, Shenzhen, China – ZTE Corporation ("ZTE") (H share stock code: 0763.HK / A share stock code: 000063.SZ), a publicly-listed global provider of telecommunications equipment, network solutions and mobile devices, has demonstrated 400G ultra-long high-speed transmission at the annual Optical Fiber Communication Conference (OFC) held in San Francisco, USA, on March 14th, 2014.

ZTE has used its patented technology to achieve 20 DWDM (dense wavelength division multiplexing) channels of 400Gbps single-carrier polarisation multiplexing and quadrature phase shift keying (QPSK) signals to successfully transmit to 3600km in standard single-mode fiber when the spectrum efficiency is improved to 4b/s/H.

The system consists of 36 segments, each covering 100km, supporting a total transmission distance of 3600km, which proves the feasibility of 400G deployment over a single carrier in future long-haul system. The system has the industry's highest Baud rate of 110G baud and standard 100GHz ITU-T channel grid with a single coherent receiver. The result has been published in a post-deadline paper of OFC 2014.

Operators

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Home > Network Design > Sprint, Ciena test 400G fiber-optic network link

Sprint, Ciena test 400G fiber-optic network link

August 19, 2013
Author Stephen Hardy
Editorial Director and Associate Publisher

Sprint (NYSE:S) and Ciena (NASDAQ: CIEN) have made good on a promise made last year to trial 400-Gbps technology on the carrier's backbone network (see **"Sprint upgrades network, sets 400G trial with Ciena"**). The two companies add that Sprint has upgraded a **fiber-optic network** link between Chicago and Ft. Worth, TX, to 100 Gbps on the basis of a different field test.

The 400-Gbps trial run ended last month. The demonstration saw Sprint apply 400-Gbps technology to its Ciena 6500s somewhere in Silicon Valley. The 400-Gbps traffic ran alongside existing live channels and validated the readiness of its network to handle such data rates when demand dictates.

"Customers have expressed their hunger for higher-speed networks to support their substantial data needs, which we project will only continue to grow exponentially," said Wayne Ward, vice president-business and product development, Sprint. "The 400-Gbps trial demonstrates our ability to offer higher speeds with our existing fiber, which means that our customers can feel assured that our network is future-proofed to meet their needs as they evolve. The delivery of 100-Gbps and 400-Gbps speeds will be critical as we launch our Ethernet Wave Services and support a growing wireless infrastructure."

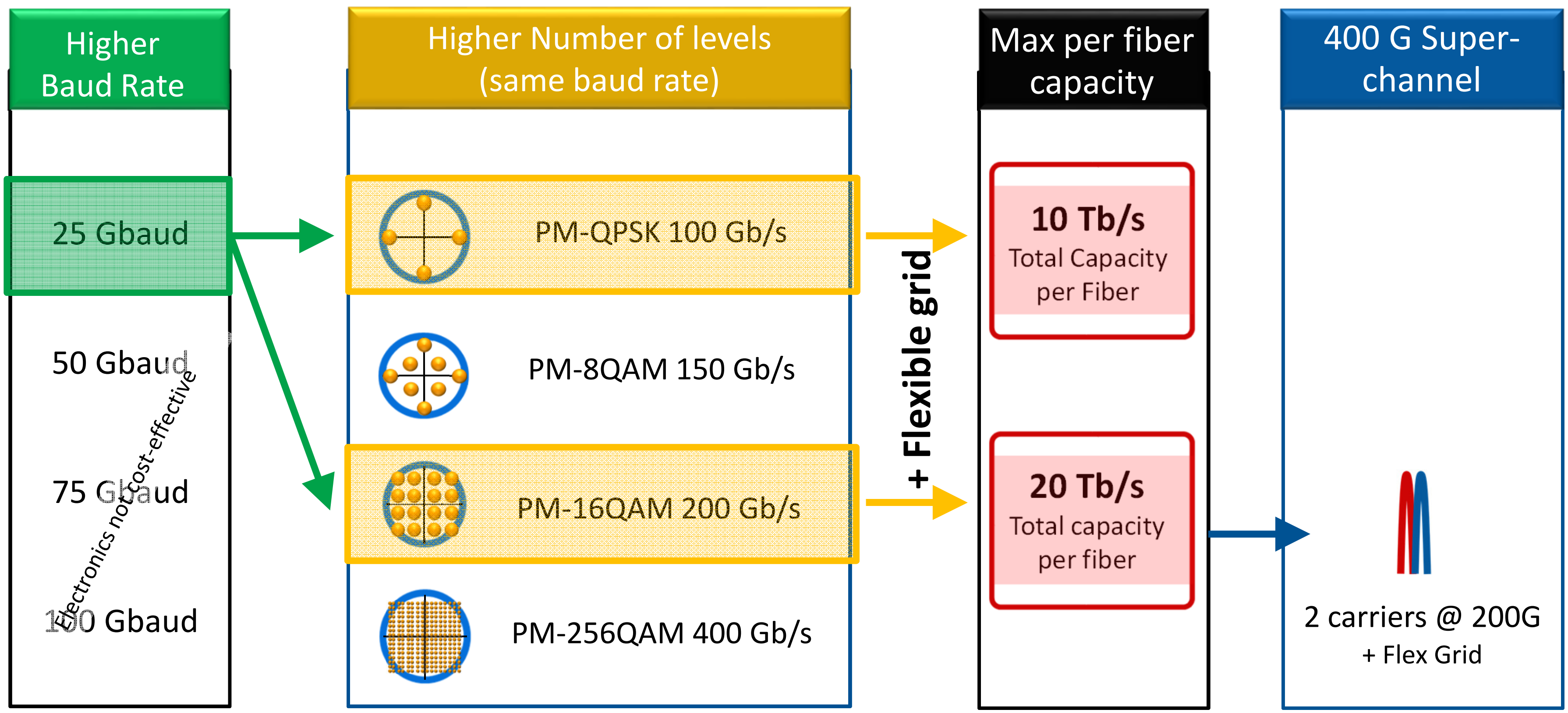
Meanwhile, the 100-Gbps test demonstrated the ability to sustain this data rate over 2100 km without regeneration. Sprint is now running 100 Gbps between the Illinois and Texas end points, while the **coherent transmission** technology is now "integrated into the Sprint optical network infrastructures," the two companies say.

The fiber-optic network enhancements form part of Sprint's Network Vision initiative. The effort seeks to consolidate multiple network technologies into one new, seamless network that will improve efficiency and enhance network coverage, call quality, and data speeds. Network Vision also aims for enhanced scalability and performance.

For more information on high-speed transmission systems and suppliers, **visit the Lightwave Buyer's Guide**.

But What is 400G in Reality?

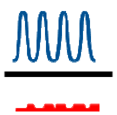
400G actually only doubles total fiber capacity over 100G



400G super-channels only represents a x2 improvement in per fiber capacity
Not sufficient to address the approaching data avalanche

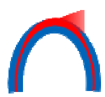
Conclusions

- Data-rich applications will force operators to transmission solutions that deliver even higher capacity networks

$OSNR_{out} =$ 

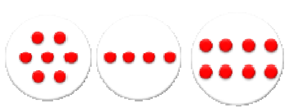
- In the backbone, maximizing OSNR is paramount
  - Fibers with ultra-low loss and large effective area

Macrobend

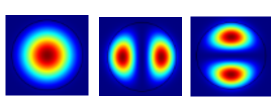


- In the access, improved bending resistance is paramount
  - Even more resistance required if fiber is taken inside the building

Multi-core fibers



Few-moded fibers



- Transmission technology may be starting to reach the edges of the envelope
  - Fiber attenuation approaching theoretical limits for practical mass-production
  - Multi-Core and Few-Moded fibers will need to overcome huge challenges in production and installation methods
  - Further increases in channel speed appear to come with unacceptable trade-offs on complexity and reach

What Matters As Capacity Demands Increase And Networks Evolve

Q What is <u>the</u> proven technology option for delivering more and better data rich services?

A High performing optical fiber

… and lots of it


CORNING
Thank You