

The Super Connected World: Optical Fiber Advances and Next Gen Backbone, Mobile Backhaul, and Access Networks

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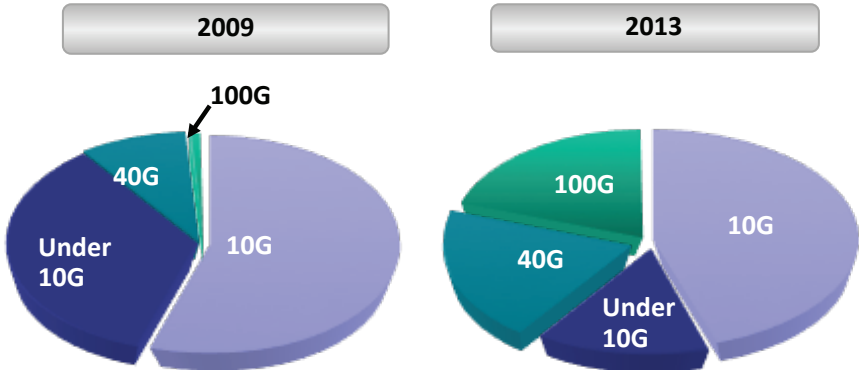
Introduction

As the ways we communicate and are connected with one another continue to evolve at pace, we are all becoming used to living in a super-connected world. Our societies are changing thanks to social networks, cloud computing, video streaming, and television à la carte. However, the ever increasing number of bandwidth-hungry applications places unprecedented levels of pressure on networks from the backbone to the access. As such, it is necessary to look at this world not from the perspective of the latest smart phone or “app”, but from the fundamental technology at the foundation of this super connectivity: namely optical fiber. This article explores the latest innovations in optical fiber technology that provide the telecommunications’ industry with high-capacity, technology-robust and low-latency solutions for backbone, metro and access networks, while also reducing costs to ensure carrier profitability.

Fiber Innovation: the foundation of next generation networks

In order to enable bandwidth-hungry applications, high-speed broadband access is being deployed in countries world-wide. This in turn is fueling substantial increases in capacity demand both in metro and backbone networks, where optical transmission data rates are consequently increasing and challenging the optical fiber links at the foundation of the telecoms transmission network.

Research conducted by Infonetics (Figure 1) forecasts a significant increase in the number of links operating at 40G and 100G by 2013. Delivering such high data rates means the attenuation of optical fiber becomes a key concern. Even then however, as Figure 1 shows, almost half of the network will still be operating at 10G, where maintaining low chromatic dispersion can be the key parameter in ensuring a profitable link for the carrier. We will now explore in more detail the role that these critical factors play at 10G and higher data rates, as well as considering the additional effects of polarization mode dispersion (PMD) and latency from the perspective of the optical fibers best-suited to each scenario.



Source: Infonetics Research Inc. 2010

Figure 1: Long Haul network data rates trends analysis from Infonetics research.



Delivering High Data Rates: low attenuation fibers and the OSNR challenge

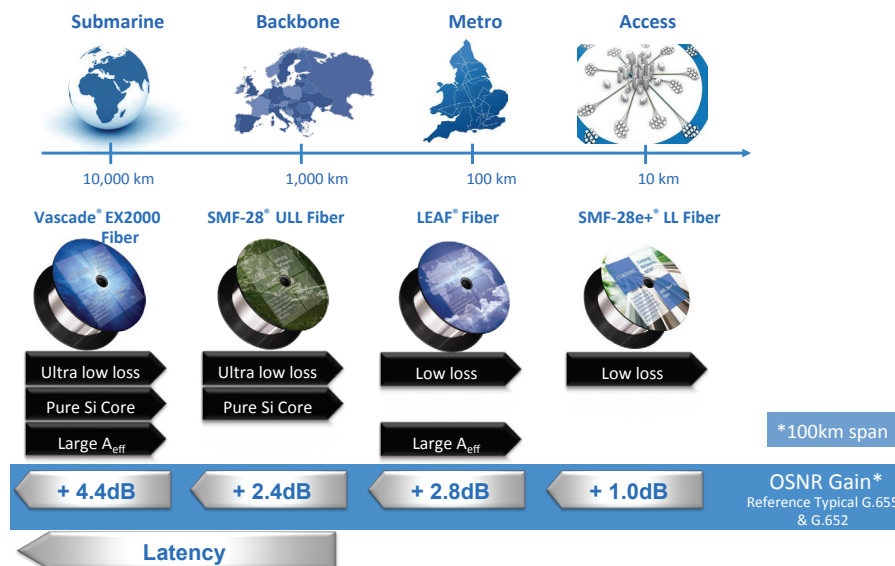
If we focus on the challenge of delivering high data rates, a basic rule of thumb for a scenario where you do not change the modulation format, is that each tenfold increase in data rate requires a 10dB increase in optical signal to noise ratio (OSNR). So in order to migrate from 10Gb/s to 100Gb/s without altering the optical transmission system, we must find an additional 10dB of OSNR for the signal quality and bit error rate to remain equivalent. Recent progressions such as advanced modulation formats and advanced digital signal processing (DSP) and coherent systems have proved successful in achieving effective OSNR gains (circa 5dB) but for some network links this may not be enough to deliver data rates beyond 100G or low cost non-coherent 100G. So the question is; can fiber innovation deliver OSNR gains to enable lower cost and/or higher data rate next generation networks?

The OSNR of a system is firstly proportional to the optimum signal power in the fiber, which itself is proportional to the effective area of the fiber. Secondly, the OSNR is inversely proportional to the total attenuation of the system, which in the case of the fiber is due to signal attenuation or loss in the fiber, which will increase with span length. Thus, to improve OSNR through fiber innovation, we must increase fiber effective area and/or reduce signal attenuation.

It is important to note though that while reducing the attenuation will have no impact on the standards compliance of a fiber, increasing the fiber's effective area can mean it quickly becomes non-compliant with the basic terrestrial ITU fibre standards, for example G.652 and G.655. This means that different application scenarios place different boundaries on fiber innovation.

In submarine networks, transmission lengths are long so transmission loss is of paramount importance. Moreover, custom greenfield builds are the norm so standards compliance is less of a concern. This enables the use of very large effective area fibers, like Corning's Vascade® EX2000, which with its larger effective area and pure silica core enables ultra-low loss and delivers significant OSNR gain (up to 4.4dB relative to a standard G.652 fiber over a 100km span).

In terrestrial systems, compliance with existing fiber standards becomes essential due to the need for inter-compatibility with legacy networks. For this reason, increasing the effective area is not possible and efforts must focus on fiber loss reduction in order to achieve OSNR gain. Recognising this, Corning has developed proprietary low-loss fiber technology which it has applied to its G.652 and G.655 compliant products. One fiber of note well-suited to terrestrial systems is Corning SMF-28® ULL fiber which delivers ultra-low loss, but does not have an expanded effective area due to the need to remain compliant with the G.652 fiber standard. With an attenuation specification of 0.17dB/km at 1550nm, relative to a best-in-class G.652 standard single mode product, this ultra-low-loss SMF-28® ULL fiber will deliver 2.4dB of OSNR gain over a 100km span. Corning's other G.652.D and G.655 compliant products (SMF-28e+® LL fiber and LEAF® fiber) also feature low-loss technology and deliver an OSNR gain of 1dB and 2.8dB respectively relative to best-in-class G.652.D and G.655 fibres, whilst remaining completely standards compliant (note here that LEAF® fiber continues to benefit from its larger effective area (0.8dB gain) relative to typical G.655 fibres, but an effective area which by nature of its low 1550nm dispersion feature is always lower than a G.652 fibre).



2 | Figure 2: OSNR gain of low attenuation Corning fibers relative to standard G.655 and G.652 fibers.

Interestingly, the pure silica core that is a feature of SMF-28® ULL Fiber and Vascade® EX2000 Fiber has a lower group index which delivers the further benefit of lower latency. This is a critical parameter which affords vital advantages in certain telecommunications settings.

Low Attenuation Fibers: How Your Network Can Benefit

By simply lowering the attenuation of an optical fiber you can deliver OSNR gains that have real benefits in terms of network capacity, performance, cost, and technology robustness.

i. Focus on Ultimate Capacity

Lower attenuation delivers more OSNR margin for upgrading to 40G and 100G and beyond, such that lower cost transmission design can sometimes be used. Consider a standard optical network transmission system with a transceiver at one end sending data to a receiver at the far end, across a series of spans of 80 to 100km each with a signal boosting amplifier stage located at the end of each span. Upgrading this system to a higher data rate could compromise its reach, meaning that an additional optical-to-electric regeneration stage might need to be included part-way along the link at considerable cost to the operator. However, the deployment of a low-loss fiber could enable sufficient spare margin to allow this network to be upgraded to a higher data rate in the future with minimal or no compromise on the original link length.

Corning tested its latest large effective area and low-loss optical fiber Vascade® EX3000 fiber in a 112Gb/s link, with sixteen channels, 100km spans and EDFA amplification only. The reach capacity at this high data rate was an impressive 7200km, the longest distance recorded for this type of configuration, clearly demonstrating that low attenuation and large effective area offer significant benefits in terms of reach at high data rates.¹

However, we may wish to use a G.652 compliant fiber with a standard effective area. Figure 3 shows a 100G demonstration by Ciena with even longer 125km spans using Corning’s G.652 standards - compliant SMF-28® ULL fiber that achieved a reach of 1500km. This demonstration showed that the ultra-low attenuation attribute on its own (as is a feature of this fiber) can extend distances by a very valuable 30 to 35%.

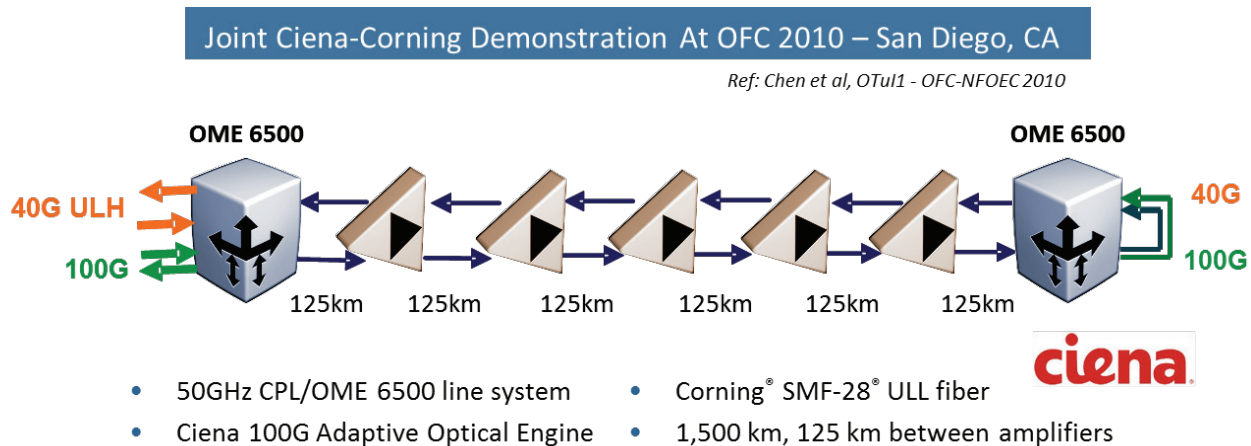


Figure 3: Joint Ciena-Corning Demonstration with Corning SMF-28® ULL Fiber.

ii. Focus on Performance

In the backbone, lower attenuation can enable extended link lengths and EDFA elimination. In access networks, it can be the key enabler for central office consolidation and extended subscriber coverage. If we consider a basic transmission system deploying low loss G.655 or G.652 fiber instead of a standard equivalent, the reduction in fiber attenuation could enable system simplification through the elimination of an amplifier stage. Either this, or the reach of the system at a given data rate could be extended. Both possibilities though equate to a simpler, more cost-effective system.

In a network deployment in EMEA a carrier deployed a ring network between three cities using Corning SMF-28® ULL fiber, with distances between each city ranging from 135km to 145km. Though the carrier paid a premium for this innovative 48-fiber count cable, this ultra-low loss fiber gave the carrier up to a 4.8dB advantage in span loss (compared to standard G.652 fiber) and helped them avoid deploying three amplifier sites in remote areas which would also be very costly to build, power, and cool.

Furthermore, as each fiber was lit the carrier made additional savings from avoiding having to install three additional amplifiers on each fiber. This eventually yielded a saving of more than \$8M once the cable was fully lit, thus allowing the carrier to achieve optimum link performance and subsequent reductions in CAPEX and OPEX.

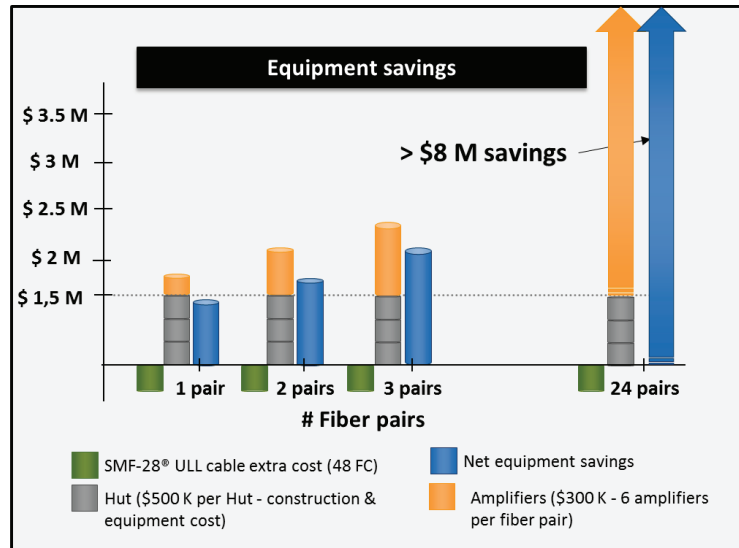


Figure 4. Equipment savings by using Corning SMF-28® ULL Fiber in a backbone ring network.

Another interesting scenario where the benefits of lower attenuation fibers can be observed is in access networks. The trend towards central office consolidation coupled with initiatives often driven by governments to serve cities and rural areas alike with fast broadband access is resulting in much longer link lengths than originally conceived (see Figure 5) and risk of increased areas without coverage (“not-spots”). Standards for extended reach systems (e.g. Class C GPON) with higher power loss budgets that ensure customer connection have been developed, but even these have their limitations in total reach and require incremental capital spend on advanced electronics.

Advances in optical fiber can help here. Despite the much shorter link distances involved in access networks, a simple reduction in attenuation on a basic G.652.D fiber (such as Corning SMF-28e+® LL fiber) can deliver significant additional reach (~10% increase) and subscriber coverage (up to 20% more coverage area), easing transition to central office consolidation and delivering additional network margin to facilitate network upgrades (like higher data rates or pre-connectorized optical cabling solutions).

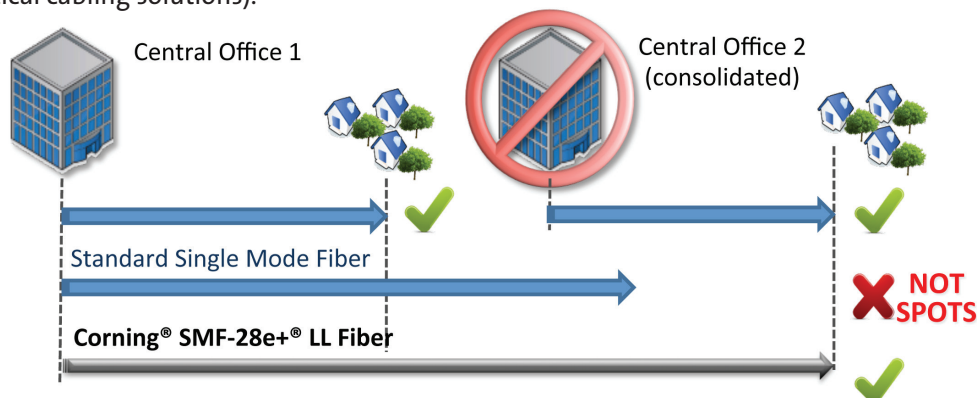


Figure 5. Central office consolidation: One of the benefits of low attenuation in access networks.

iii. Technology Robustness

Back in the backbone or core network, here low-loss technology can also improve technology robustness, particularly considering the rising popularity of all-optical switching. Generalizing, we could say that the penalty incurred, or higher attenuation introduced by an optical switch typically reduces the reach of a system by one span. However, the additional OSNR margin that can be gained by using a low-loss fiber can be sufficient to enable the insertion of an optical switch with minimum impact on reach or number of spans.

Lower Dispersion in Next Generation Applications

As the previously mentioned research from Infonetics shows, whilst some networks are already operating at 40G and 100G speeds, a significant number of networks remain at 10G with some vision towards 40G. For those routes with modest traffic demand, investing in expensive advanced optical processing such as coherent detection or complex modulations might not be the most cost-effective solution. At this level, simplification of the link to enable a cost-effective solution is the key; it is here that non-zero dispersion-shifted G.655 fibers are most effective.

The benefit of using lower dispersion optical fibers to enable system simplification (via the removal of dispersion compensation modules, or DCMs) is well understood. In a basic 560km, eight-span 10G optical transmission link set up with G.652 fiber, switching to G.655 fiber would mean the five dispersion compensation modules (DCMs) required in the original architecture could be removed. This switch would also mean that the dual stage amplifiers at each of these points could be downgraded to cheaper single stage amplifiers, with the second stage no longer being required to make up for the loss of a DCM.

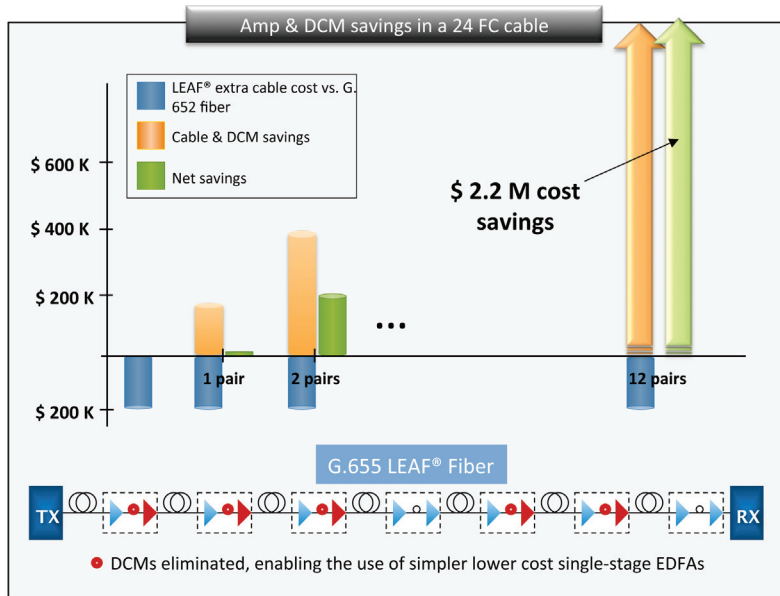


Figure 6. System savings using Corning LEAF® G.655 fiber over a 560km link with a 24 fiber count cable.

Although the G.655 cable comes at a premium, when the first pair of a 24-fiber count cable is lit on day one, the equipment savings immediately cover the cable premium to yield a net positive savings solution, with savings reaching over \$2 M in equipment savings once the 12 fiber pairs are lit. This explains why G.655 fibers have been and continue to be popular in certain applications and why Corning has sold over 30 million kilometres of its low dispersion product, Corning® LEAF® fiber to date.

Lower Polarisation Mode Dispersion

Deploying a fiber with lower polarization mode dispersion in long haul links has always been a sensible idea. Low PMD levels act as an insurance policy against possible PMD challenges that could be faced by future technologies guaranteeing that the link won't become obsolete as soon as it needs to be upgraded to higher data rates or migrated to new transmission technologies. But in addition, deploying fibers with low PMD also allows for more simplified 40G systems, without having to rely quite as much on digital signal processing at the receiver to correct the effect of PMD in the signal.

The Importance of Latency in Long Haul Links

Latency describes the delay between a signal being transmitted and received and for high frequency traders associated with financial markets, this parameter is a big issue. Today high-frequency trading firms pay a premium for a latency advantage as just a few microseconds of delay in receiving trading information relative to a competitor can result in loss of deals with big financial impact. Latency in the link appears as a result of the delay incurred by different elements: the signal processing in the electronics, the amplifiers, the DCMs (if using any) and there is also delay introduced by optical transmission of the signal along the fiber, which is directly proportional to the length of the link; the longer the link, the more delay.

Looking at the relative latency contributions from each of the above factors, it becomes apparent that the biggest contribution comes from the transmission fibers and as the transmission length goes over 10km, the fiber becomes almost wholly responsible for latency. This delay is directly proportional to the group index of the fiber and so reducing the group index can lower the latency contribution from the transmission fiber.

The pure silica core of Corning's ultra-low-loss products (like SMF-28® ULL fiber and Vascade® EX2000 fiber) have a 0.4% lower group index relative to traditional fibers made with a Si-Ge core. This may not seem significant but over a return trip across the Atlantic Ocean, the difference can enable a 150 μ s advantage, which is highly attractive to traders working between the London and New York stock exchanges.

The Role of Optical Fiber in Delivering the Networks of the Future

In this paper we have observed how innovation and advances in some critical attributes of optical fiber (namely attenuation, dispersion, PMD, and group index) can make a difference to a network. In particular, we have witnessed how lower attenuation can deliver higher OSNR and how optimized selection of fiber type can enable lower costs and ultimate network performance by enabling the following next generation network requirements:

- Ultimate capacity
- Network simplification
- Higher performance
- Technology robustness
- Lower latency

We are driving relentlessly towards a super-connected world, greatly enabled by broadband access technologies. This in turn is driving soaring capacity demand throughout access, metro, and backbone networks. For such a super-connected future, innovation matters. When it comes to the future of optical fiber, the overriding conclusion is that fiber loss (attenuation), dispersion, PMD, and latency matter. Innovation is at the very heart of Corning, and Corning's recent innovations have delivered an enhanced next generation portfolio of fibers featuring Corning's industry-leading low-loss technology combined with enhanced performance in PMD, dispersion, and latency. These next generation fibers will facilitate the cost and performance gains required for the networks of the future and ultimately enable the super-connected world.

References

¹ J.D. Dowie *et al* '112 Gb/s PM-QPSK Transmission up to 6000 km with 200 km Amplifier Spacing and a Hybrid Fiber Span Configuration' ECOC Technical Digest, paper NTR 1100243 (2011)

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