Xtera

Options for Increasing Capacity in Subsea Systems

Drawing on his early career work on fibre and cable design, Stuart Barnes shares his perspective on the drive for more bandwidth in submarine links. This white paper looks to debunk what can and cannot be done as we approach the Shannon Limit.

1. Preamble

Since the introduction of optical submarine systems in the 1980's the industry has enjoyed a 4X increase in bandwidth every 3-5 years. The periodicity has been governed by a combination of technological and economic issues. Starting with 140Mbit/s plesiochronous regenerative systems through to today's N x 400Gbit/s coherent detection technologies the operators have been able to enjoy multiples of bandwidth at approximately the same link costs, but the party is now over for advances on a single fibre as we approach the physical limits proscribed by Shannon's Law. With the latest chips and clever fibre design long transoceanic links can operated within a dB or so of the physical limit. This has coincided unfortunately with a boom in demand, largely driven by the OTT's.

This white paper considers the choices now facing the industry and particularly the impact of these on powering tomorrow's systems. This issue was brought to the industries' attention back in Paris (SubOptic 2013) by Xtera's CTO Tony Frisch. This paper discusses the following; amplifier design, fibre & cable and system implications – all of which are inexorably intertwined.

Finally, as there is huge downward price pressure pushing the industry towards commoditisation, this paper reviews how this may influence technology choices in the foreseeable future.

2. Amplifier Design

There are essentially three options facing system vendors with respect to amplifier design; all Raman, Hybrid Raman EDFA and pure EDFA (C and C+L). Also, there is now a considerable level of research being carried out on new amplifier concepts as we are still only using a fraction of the 3rd Window, see Section 2d.

a. Pure EDFA

Starting with the traditional approach - pure EDFA. Erbium Doped Fibre Amplification techniques originated from a UK Government Sponsored JOERS (Joint Opto-Electronic Research) programme in the 1980's and pioneered by Southampton University. This was the first major technological breakthrough in the 4X cycle. Originally single channel, the technology was soon coupled with Wavelength Division Multiplexing (WDM) to finally fill the whole C Band of the 3rd Window, approximately 40nm in bandwidth. More recently there has been a move to sit further channels alongside the C Band in the lower L Band. In particular TE Subcom have several publications concerning this approach[1].

This is a logical extension of today's EDFA approach. The power consumption of the L Band portion is a little higher, but not sufficient to be highly penalising. There has to be a small guard band between the 2 amplifiers spectrally, but SubCom appear to have made progress minimising this (See Fig. 1). The other drawbacks are that the technique will not scale effectively beyond 70nm bandwidth and in the absence of active supervisory the amplifiers cannot be independently managed. For instance, if the C Band amplifier ages and the L Band doesn't then tweaking the line current/voltage may not have a net beneficial effect.

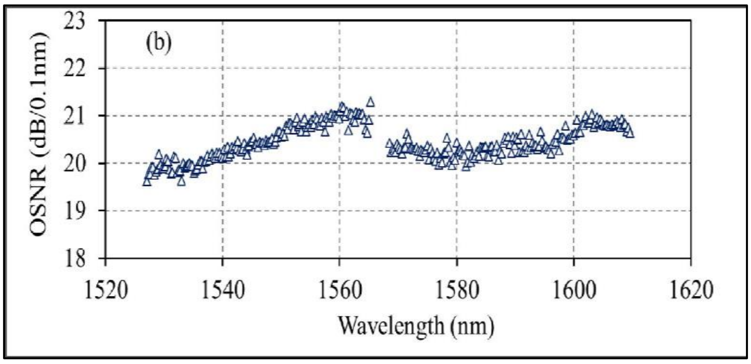

Figure 1 OSNR versus Wavelength for C+L lumped amplifiers (Cai et al[2])

b. All Raman

There is little to discuss regarding an all Raman solution in the context of long-haul submarine links as the technology is very power hungry. However, where power is not a constraint this technology has been found extremely useful in both terrestrial and unrepeatered submarine links, particularly those that are more challenging in terms of distance.

c. Hybrid Raman EDFA

One technique that is gaining some traction is a Hybrid Raman EDFA approach, wherein the EDFA gain is complemented with some "light" Raman amplification. By judicious use of backward Raman amplification in the fibre before a repeater one is able to use this phenomena to either increase the span between repeaters or make a C + L repeater of similar or greater bandwidth to the pair of adjacent amplifiers described in 2.a above.

Xtera have now installed a number of systems using this technology, the earliest one with a bandwidth of ~70 nm, and have carefully monitored Raman pump consumption, which is at a lower current than those used to pump the doped fibre. These systems operate at around 700mA, and there is considerable evidence that such systems could be run at significantly lower line currents in the future – we have shown that they can actually be operated as low as 500mA. This can therefore save upwards of 0.5kW/1000km based on 1Amp line current used historically. Amplifier design is also a potential route to major power savings. It was traditional to build in margin to account for component ageing, in particular the semiconductor pumps. We now have two significant inputs to this argument. Firstly, there is considerably more ageing data that can enable an adjustment in a positive direction. Coupled with a major rethink in system lifetime we can see significant power savings.

There is, of course, a power increase with a broadband hybrid amplifier, but for many systems this is not a problem as the length/fibre count equation means that the net system power requirement is comfortably within the cable rating envelope. All manufacturers rate the maximum cable voltage and there is some disparity due to small differences in interpretation of the kV^n ageing relationship.

It is clear that there is minimal power disadvantage to the Hybrid approach, certainly with the narrowband application. The attributes of this approach are as follows:

- The low Noise Figure of the amplifier can increase the spans over the standard EDFA. With an average NF of 2.5dB and with low loss fibre of ≈0.16dB/km (note Xtera can use low loss standard SMF in nearly all applications of the Hybrid Raman Amplifier) then spans can be increased by at least 20km.
- The use of standard SMF for the majority of applications has a major economic benefit especially for very high fibre count systems.
- Xtera can use the use the fact that their repeaters have two pump types to compensate for any tilt changes in the gain profile, which can occur particularly in the case of a non-optimal repair. This of course has a further economic benefit in very long systems where for other designs extra underwater devices are required to mitigate for these effects.
- Xtera’s proprietary active supervisory and control system, which can be used to switch the BU’s, separates the line powering from management of ageing and switching, further de-risking the system throughout the life span.
- The approach is scalable beyond 100nm bandwidth.

d. New amplifier techniques

With C+L we are still only utilising a portion of the third window. There is now a considerable interest in the more complete use of the third optical window, particularly in terrestrial applications, where fibre although easier to install than in submarine (see below) there are many applications where it is easier to install more new amplifiers rather than new fibre. There are several new UK academic programmes funding work in this space.

3. The fibre and cable perspective

Until recently submarine cables have comprised a maximum of 8 fibre pairs, and this was a one-off quickly reduced to significantly less on average. There is considerable pressure from Operators to reduce system prices and increase link bandwidths significantly. A number of content providers have been pushing Space Division Multiplexing, which has metamorphosed from Multimode Fibre (distance limited) to Multicore Fibre (not available for many years) to more fibres per cable.

With the undoubted improvements in cable design since the introduction of the steel inner tube, cabling losses are minimal even with large effective area fibres, which is essential for minimising non-linear penalties in very long systems. However, minimising micro-bending effects is highly dependent on the polymeric coating on optical fibres (see Fig 2 below), and the combination of thin coatings and large effective area fibres may be toxic.

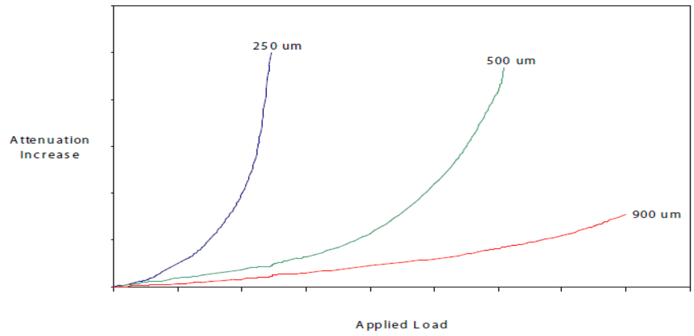

Figure 2 Effect of Coating thickness on micro-bending (Note that the cladding size is 125micron)

Until cabling trials have been carried out (over the next couple of years) the industry won't truly know what penalties may arise from these packed cores. What is certain is that the Hybrid Raman EDFA repeater works with single mode fibre (type SMF28) which is inherently less bend sensitive than higher effective area products and furthermore less expensive than large core fibre.

4. Concluding Remarks

The major challenge facing our industry today is how to achieve more bandwidth per cable, however it *can* be delivered within the confines of available power. Betting the future on multicore fibres is potentially a major risk. There is a place for these in short links, where loss, PMD, mitigation of non-linear impairments and large inner core sizes are not critical.

Clearly, there is headroom for more fibres, but the industry should be more circumspect about very large fibre counts, particularly as fibre costs will dominate the overall cost in relation to everything else. And from an overall commercial perspective, and including the installation component, then there must be an exchange between more fibres and more cables, particularly as multiple cables offers greater route diversity. Smaller fibres are a logical progression, but cabling these will not be trivial. Other factors come into play with bigger cables, not least the issue of neutral buoyancy.

This paper has shown that power consumption is not really an issue with the pump component of C+L amplifiers, and these products are available today. Hybrid Raman EDFA is field proven and the alternative C+L approach will be going into service imminently. Both these techniques can double the bandwidth per fibre pair, perhaps quite a lot more with the Hybrid approach.

Amplifier design has been lagging behind other advances in system design, and the industry has been extremely conservative from the amplifier ageing and line current perspectives, and these would appear to offer further major opportunities in power utilisation.

References

1. "70.4 Tb/s Capacity over 7,600 km in C+L Band Using Coded Modulation with Hybrid Constellation Shaping and Nonlinear Compensation" - J. -X. Cai et. al., Th5B.2, OFC 2017.
2. An Overview of Microbending and Macrobending in Optical Fibers – John Jay. Corning White Paper (Dec 2012)

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About the Author

Stuart Barnes is the Chairman of Xtera. After graduating from Queen Mary College, London University with BSc (Hons) and PhD in Engineering Stuart Barnes joined Standard Telecommunications Ltd, the Research Subsidiary of STC. After 7 years in Research, including 3 years supporting development of STC Submarine Systems first Optical Repeater, he then was involved in turnaround activities in the terrestrial fibre and cable divisions (market share increased from 5% to 50%).

Then, in STC Submarine Systems, he went on to become Technical Director in 1995, where he was responsible for the development of STC's second optical repeater. After the acquisition of the Submarine Group by Alcatel he moved to Paris to head up Alcatel's Optical Recherche Group. In 1999 he Founded Ilotron (UK), after a short period with Atlas Venture as an ER he co-founded Azea Networks in 2001, who merged with Xtera Communications Inc. in 2007. He is Visiting Professor at Southampton University and an Adviser to The School of Photonics, Aston University.