BENEFITS OF 40/100G IN SUBMARINE SYSTEMS

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Abstract: Higher data rates offer improvements in cost of capacity, density of terminal equipment, and power dissipation. In this paper, we describe trade-offs among initial cost, life time cost, modulation formats, and coherent techniques. We discuss the benefits of 40/100G equipment technology for new systems and for upgrades, and as a practical example, describe our next generation of 40G transmission equipment.

1. INTRODUCTION

In today's submarine systems, 10G traffic is prevalent while the need for 40G is imminent. Newer higher data rate submarine terminal equipment has several advantages over the present 10G equipment, such as reduced cost per bit, increased capacity, reduced floor space per bit, and reduced power dissipation per bit. These advantages provide benefit to system owners for both newly-constructed systems as well as for upgrades. Even in the absence of an immediate need for 40G client-side traffic, the higher data rate submarine terminal equipment can be effectively utilized through the use of Muxponders. Furthermore, if those Muxponders are designed with client and protocol flexibility in mind, the upgrade path from 10G SDH to higher client rates and protocols of the future is simplified, protecting the owner's investment in transmission infrastructure.

For 40G and 100G data rates, coherent technology, such as the equipment that is presently being standardized by the Optical Internetworking Forum (OIF), will be very attractive for submarine systems, allowing substantial capacity increases when implemented in conjunction with optimized coherent submarine system designs.

This paper outlines the inherent higher data rate trade-offs and proposes that the nascent 40G equipment has reached a turning point at which 40G technology, in many cases, provides the most attractive value proposition. We discuss the benefits of 40/100G submarine equipment technology, supporting both 10G and 40G client data, for both newly constructed systems as well as for upgrades. Finally, as a practical example of equipment providing these advantages, we describe how TE SubCom's first generation of 40G equipment, based on mature DPSK technology, and second generation equipment, incorporating coherent technology, can benefit submarine system owners.

2. HIGHER DATA RATES PROVIDE VALUE FOR UNDERSEA NETWORKS

New generations of high data rate equipment provide great value for submarine systems. The main benefits are increases in capacity and decreases in cost of transmission equipment, leading to a lower cost per bit. There are also other benefits in terms of floor space, power dissipation, and ease of wavelength management. The following sections will provide examples and describe these benefits in greater detail.

2.1. COST AND CAPACITY DRIVE DEMAND

The demand for higher data rates throughout the generations of submarine systems has been motivated by potential for increases in capacity and decreases in terminal equipment costs per transmitted bit. Increased capacity on each fiber pair better amortizes the expensive construction costs of a system, and lower transmission equipment costs, over the life of the system, reduces operating expenses as the system is upgraded toward its final capacity. Furthermore, on existing systems, the ability to increase ultimate capacity through the use of newer generations of transmission equipment increases return on the original investment and better amortizes fixed maintenance costs.

Figure 1 illustrates the potential for capacity increases, assuming optimized system designs, which these higher data rate technologies provide. The area of each circle is proportional to the total capacity that can be provided using the particular technology, and all circles are plotted for the same system bandwidth. 40G Differential Phase Shift Keying (DPSK) technology has the potential to double the capacity compared to 10G, whereas coherent Dual Polarization Quaternary Phase Shift Keying (DP-QPSK) technology has the potential to further significantly increase capacity. It is important to understand that to achieve the potential capacity, a system must be optimally designed for the chosen modulation format. The ability to increase capacity on existing systems depends on the particulars of each such system, and would in most cases not meet the full potential of the technology. For the most challenging systems, it is possible that none of the higher data rate technologies would be able to provide more capacity than 10G technology, and in fact may actually provide less.

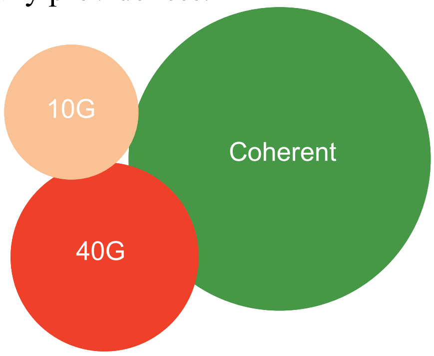

Figure 1: Capacity potential for 10G DPSK, 40G DPSK, and coherent DP-QPSK systems utilizing purpose-designed submerged plant.

Figure 2 shows an example of the life-time savings that a newly constructed system optimized for 40G DPSK can provide over that optimized for 10G.

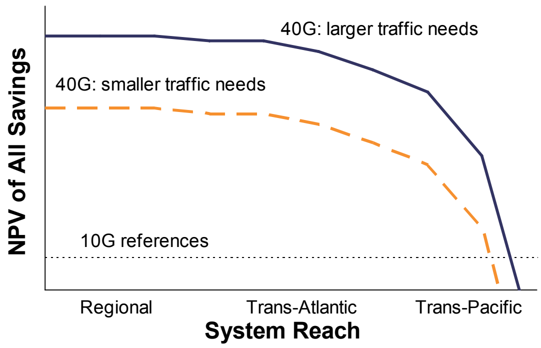

Figure 2: Higher data rates provide savings over the life of a system.

In this example the systems compared have the same ultimate capacity and 40G technology is only used to reduce the cost of terminal equipment. The savings are calculated as net present value (NPV) of all savings over the life of the system assuming a 10% discount rate. Two traffic need scenarios are shown: the example with smaller traffic needs assumes a few initially deployed channels with upgrade to full capacity taking 20 years. The example of larger traffic needs assumes a larger initial deployment with upgrade to full capacity taking 10 years. The larger the traffic needs, the bigger the benefit, but in each case there are substantial savings over the life of the system from building systems optimized for 40G rather than for 10G, up to the distance where the 40G technology works well.

The benefit of 40G, in the case where the larger ultimate capacity is needed, is even bigger. For comparison, matching the capacity of 4 fiber pairs at 40G might require 8 fiber pairs at 10G. This would make the 40G solution even more attractive than illustrated in Figure 2.

2.2. FLEXIBLE CLIENT INTERFACES PROTECTS INVESTMENT

It is expected over time that a growing percentage of high data rate traffic will be in the native Ethernet standard, the OTN protocol or in OTNe digital wrapper format. It will be necessary to gracefully accommodate the transition from 10G to 40/100G client traffic and from SDH to these Ethernet and OTN protocols.

To achieve such a graceful transition the use of configurable multi-protocol clients and replaceable client modules to accommodate Muxponder and Transponder application are needed. As traffic patterns change with time, such an approach allows the client port compliance to be changed by individual re-provisioning of any particular client port. Client ports in the Muxponder application should also be individually configurable to allow mixing of protocols as needed. Replaceable client modules allow Muxponders to be converted into Transponders as client traffic needs change. This approach, in addition, simplifies sparing and adds a level of "future-proofing". With this flexibility, each circuit pack can remain compliant to all expected standards of client traffic over its life.

2.3. HIGHER DATA RATES NEED BETTER OSNR

Increase in data rate does not come for free. Basic physics dictates that an increase in data rate (everything else unchanged) needs a corresponding increase in Optical Signal to Noise Ratio (OSNR). Present 10G submarine-quality transmission equipment is very well-optimized and already uses many advanced techniques, such as DPSK modulation and large overhead strong Forward Error Correction (FEC) codes. The increases in OSNR needed to support higher data rates can be achieved by shortening repeater spacing, utilizing transmission fiber with less loss and/or larger effective area, increasing repeater output powers, or any combination thereof. All of these options increase the cost of the submerged plant compared to that of an optimized 10G design with the same capacity, assuming 10G could provide the total capacity needed. In practice, this means that in many cases 10G-optimized systems with spectral efficiencies of 40% or less (e.g., 128x10G for a 28 nm system) can be constructed for a lower cost than equivalent 40G systems. However, as implied earlier, such 10G-optimized systems may not support 40G transmission without large loss of capacity, if at all.

Figure 3 gives an example of providing the needed OSNR by increasing repeater count in 24x40G systems relative to that of comparable 96x10G systems. Although there is a submerged plant premium as discussed earlier, there is a transmission equipment cost advantage to the higher data rate equipment. Thus, the increased cost of the submerged plant might be compensated by savings on the initially loaded channels. This is indeed the case for many systems with large initial loading. For systems with slim initial loading, 40G carries a premium, but as illustrated in Figure 2 there is a substantial long-term economic advantage.

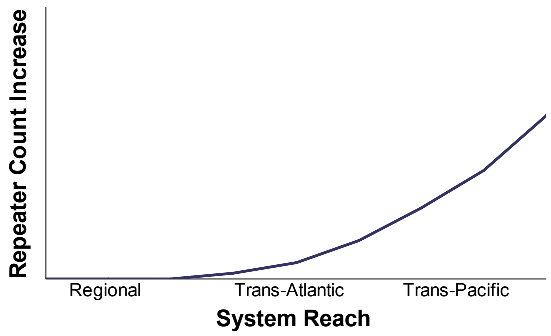

Figure 3: The increased OSNR requirements of 40G relative to 10G can be satisfied by using additional repeaters.

2.4. DIFFERENT MODULATION FORMATS HAVE DIFFERENT ADVANTAGES

For earlier generations of submarine terminal equipment, typically each supplier had a single product that satisfied all needs. Starting with the latest generation, some suppliers offered both On-Off Keying (OOK) as well as DPSK modulation formats. The main motivation for OOK terminals was to provide a less expensive solution for systems that did not need the performance of the DPSK solution. This need for differently optimized products will be more pronounced for the future generations of equipment starting with 40G. Not only will different modulation formats provide different cost-performance trade-offs, but will also have different abilities to provide the largest capacity. Often the most spectrally efficient format will also exhibit the poorest performance. Thus, in the future there will be a capacity-cost-performance trade-off for terminal equipment. A full-service provider will likely need to offer several different modulation formats to provide the best value proposition.

Figure 4 compares several coherent and non-coherent modulation formats on 10G legacy systems similar to those deployed over the last decade. The maximum supported distance is shown for each modulation format at the appropriate spectral efficiencies. The formats are ordered left to right in terms of complexity (and likely cost) of implementation.

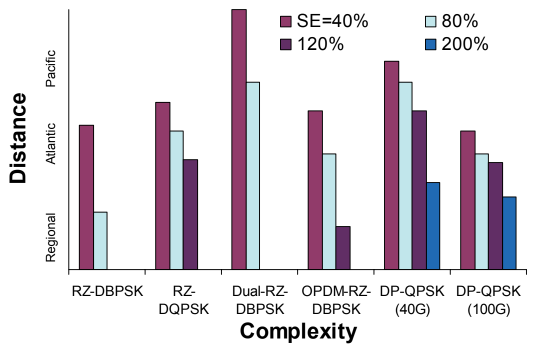

Figure 4: Many choices of modulation formats with distinct advantages in reach and spectral efficiency (SE).

As can be seen on the figure, the best performance at low spectral efficiency and high spectral efficiency is not achieved by the same modulation format. Furthermore, for the lower spectral efficiencies, coherent equipment might not perform the best on legacy systems.

The reason that coherent equipment does not outperform non-coherent equipment on legacy systems is due to its larger sensitivity to nonlinear transmission impairments [1]. The dispersion map for coherent systems can be optimized to minimize nonlinear transmission impairments, but that option does not exist for legacy systems. Due to this increased sensitivity to transmission impairments, coherent equipment technology may be more attractive to upgrade legacy systems where excess margin enables larger capacities to be realized, but less attractive to upgrade very long nonlinear systems.

2.5. COHERENT TRANSMISSION HOLDS GREAT PROMISE

The potential for very large capacities using coherent techniques requires an optimized design of the submerged plant. As explained in the previous section, coherent performance on legacy systems is limited by the increased sensitivity to transmission impairments. However, when the submerged plant design is optimized for coherent transmission, this technology offers the best performance by a significant margin [2]. Figure 5 shows an example of coherent performance on a legacy system vs. an optimized system. The optimized system substantially lowers nonlinearity and allows the coherent receiver to operate in its most efficient mode.

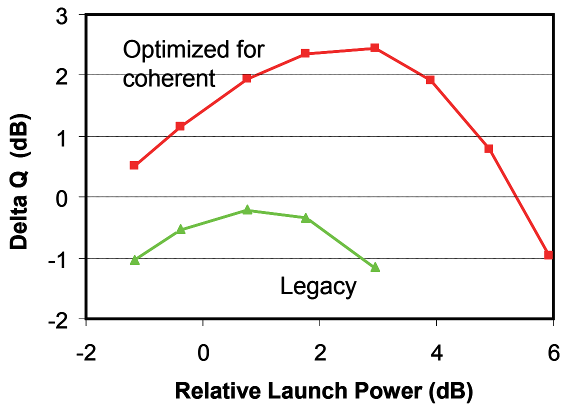

Figure 5: Coherent transmission can be substantially improved by optimized design.

The optimized system also simplifies the dispersion map. The best performance is achieved using low-loss large-effective-area positive-dispersion transmission fiber only, with no in-line dispersion management: the larger the effective area and the lower the loss, the better the performance. This dispersion map results in performance improvements and possibly fiber cost savings, but the terminal equipment must be able to compensate a few hundreds of thousands ps/nm of accumulated dispersion. Such a system would likely only be upgradeable by coherent equipment.

It is expected that once coherent equipment becomes available, 40G coherent techniques will be used initially for transoceanic distances and 100G for regional distances. As confidence is gained in these new coherent dispersion maps, simplified maps will likely be used for all systems.

3. FIRST GENERATION 40G TRANSCEIVER

As a practical example of first generation 40G terminal product, the TE SubCom product (denoted Gen 4) is now described. It is designed to provide many of the benefits discussed earlier using mature DPSK technology. The equipment increases capacity compared to that of the 10G generation, reduces power consumption per bit by 50%, and increases density fourfold or greater [3].

The Gen 4 product has firmware configurable multi-protocol clients. The port compliance includes all four contending client port transmission standards for terrestrial traffic: (a) SDH; (b) Ethernet; (c) OTN; and (d) OTNe. This compliance is achieved by simple and quick customer provisioning of the client port. See Figure 6 which illustrates the block diagram.

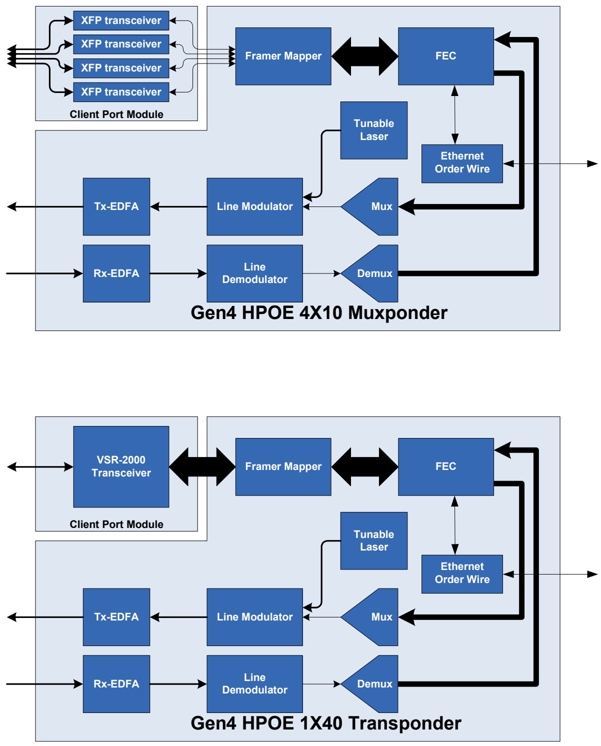

Figure 6: Block diagram

The client port is implemented as a field-removable module separately pluggable to the main portion of the circuit pack. The choice of Client Port Module (CPM) configures the product to be a 4x10G Muxponder or 1x40G Transponder. When configured as a Muxponder, the four client ports are made independently compliant to any of the four transmission standards mentioned above. The Transponder will similarly be compliant to any of the four transmission standards. Figure 7 shows the pack with the Client Port Module (CPM) partly inserted.

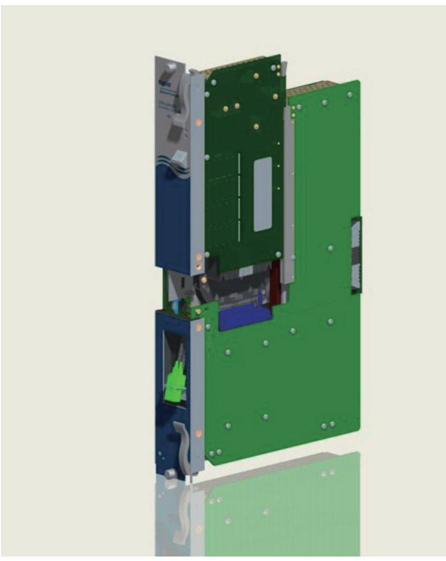

Figure 7: Mechanical drawing of a transceiver with the client port module partially inserted.

The Gen 4 transceiver product employs differential detection of carrier phase modulation. Two versions of the Gen 4 transceiver will be offered, both employing proprietary modulation formats based on pulse-shaped DPSK technology. One line modulation format has been chosen to reach trans-oceanic distances and the other has been optimized for shorter regional distances. The modulation format is fundamental to the transceiver and not field-configurable. Figure 8 illustrates the domains of performance in which each modulation format is best suited and most cost-effective.

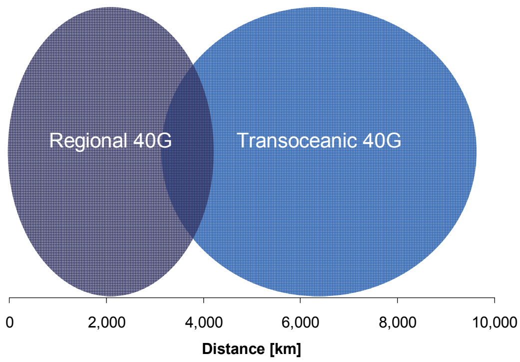

Figure 8: Preferred ranges of operation.

The Gen 4 40G terminal incorporates per-wavelength tunable dispersion compensation (TDC). This technology replaces spools of dispersion compensating fiber with a Q-penalty-free component. Automatic dispersion tuning simplifies commissioning of channels, both for initial deployments as well as for upgrades.

4. NEXT GENERATIONS OF TRANSMISSION EQUIPMENT

The next generation of transmission equipment beyond Gen4 will incorporate coherent technology, will operate at 40G and 100G, and will include the CPM for client ports. This equipment will be based on the Gen 4 platform, whose modulation formats have been chosen to ensure compatibility with this future coherent equipment.

5. CONCLUSION

The submarine market has reached a turning point where 40G and selective use of 100G will add significant value. These newer technologies enable significant capacity increases and reductions in owners' overall costs over system lifetime. At the time of initial installation, there might be a small cost premium, but that premium enables a more competitive long term solution. A system optimized for 10G might provide the absolute lowest cost, but might preclude operating with the newer generations of terminal equipment. Coherent equipment has many substantial benefits, but suffers more from transmission impairments, and thus needs new optimized submerged plant designs to reach its full potential. For upgrades of systems with excess margin, coherent technology may provide value by increasing ultimate capacity. For long nonlinear legacy systems, non-coherent equipment appears to provide more value.

A first generation 40G terminal is described with intrinsic flexibility to provide a graceful path from the bit rates and protocols of today to those of tomorrow.

6. REFERENCES

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