UNREPEATERED SYSTEMS – WHEN TO SWITCH TO A DIFFERENT TECHNOLOGY

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Abstract: This paper aims at explaining how one can compare unrepeatered to repeatered solutions for short haul applications in light of their costs and performance management. It will be demonstrated that repeatered systems could today be an alternative to unrepeatered systems in the 400 km range depending on the customer's cost of ownership and risk philosophy. The future swap over ranges will be analysed based upon the unrepeatered system technology roadmap.

1. STATE OF THE ART SUBSEA SYSTEMS

Owing to recent development in the electronics and optics areas, the distance capability of unrepeatered systems has dramatically increased in the last couple of years, reaching spans of 400 km and beyond [1]. In the meantime, progress in Dense Wavelength Division Multiplexing (DWDM) technology has allowed to consider very high capacity systems in the range of several Terabit/s per fiber pair [2]. To reach very long distances, unrepeatered systems need a set of high power units, like optical post-amplifiers increasing the aggregate signal power up to about 1 W, and Raman pumps using the line fiber as an amplification medium to get around 30 dB gain at the receiver side. More advanced systems may utilize remote amplification which consists in pumping an erbium doped fiber located in the submerged cable at ~100 km from the receiver and/or from the transmit side from the terminal equipment. However, for a given unrepeatered system architecture, physics dictate that the higher the capacity, the shorter the span and today, but for a few laboratory hero-experiments, even the most advanced and complex system architecture cannot bridge single-spans longer than ~500 km [3].

On the opposite, traditional repeatered submarine systems are designed to address even higher capacity over several thousands of kilometers, using in-line amplifiers [4]. For such systems, an electrical Power Feeding Equipment (PFE) powers the evenly spaced submerged repeaters. Equipped with "submarine" line terminals, repeatered submarine systems can reach 13 000 km [5]. However, if the transmission distance is limited to about 1000 – 1500 km, terrestrial line terminals simpler may be used to reduce the system cost.

Figure 1 depicts the typical architecture of a ~ 400 km transmission system with and without in-line amplifiers.

Since the unrepeatered systems reach is limited, repeatered systems have to be used when the transmission distance drives the unrepeatered system's margin towards zero. From a technical viewpoint the logic is clear: as the distance increases, repeatered systems will get deployed any time unrepeatered systems cannot meet the required optical link budget. At the same time, however, unrepeatered systems are less expensive than repeatered systems, so they will be preferred if they can be implemented [6]. This begs the question: is it possible to develop a "short-haul" repeatered system which can approach the low cost of unrepeatered systems ?

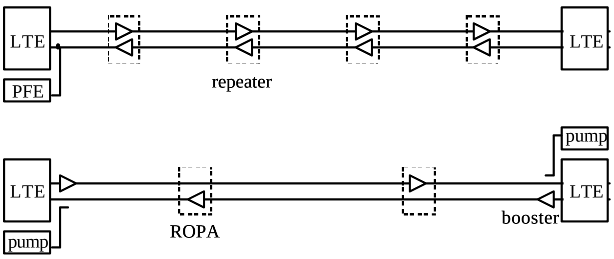


Figure 1: typical architecture of repeatered (top) and unrepeatered (bottom) transmission systems

2. REPEATERED VERSUS UNREPEATERED TRADE-OFFS

For ranges as short as 400 to 500 km, there are sound technical reasons to modify the repeatered solution. This short haul solution will be designated as "Light Repeatered" (LR). The main deltas with the "traditional" repeatered (TR) systems will be the following:

- (2 pump, 17 nm) versus (4 pump, 34 nm) repeaters;
- 3 kV versus 12 kV insulated cable;
- Use of a terrestrial terminal and no line supervisory.

The unrepeatered (UR) systems ready for deployment in 2004 fare as such:

- 2.5 Gb/s, 425 km, 8 lambdas, 3.5 dB margin
- 10 Gb/s, 400 km, 4 lambdas, 3.5 dB margin.

The comparison will be based on the following systems:

Parameter(s)	UR	LR	TR
Fibre Pair	6	1	1
Channel per fp @ 2.5 Gb/s	8	42	N/A
Channel per fp @ 10 Gb/s	4	42	126
Bandwidth	17 nm	17 nm	34 nm
Repeater Count @ 2.5 Gb/s	2 ROPAs	5	N/A
Repeater Count @ 10 Gb/s	2 ROPAs	4	4
Power Feeding Equipment	N/A	Un-Duplicated	Duplicated
Line Terminal	Terrestrial	Terrestrial	Submarine

Table 1: Architecture of systems considered

2.1) Cost Comparison

The relative system cost will be presented as well as the cost delta per work packages.

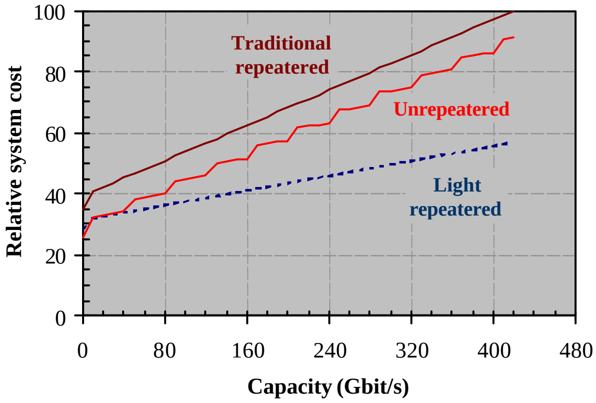


Figure 3: Relative system cost for a 10 Gbit/s line rate

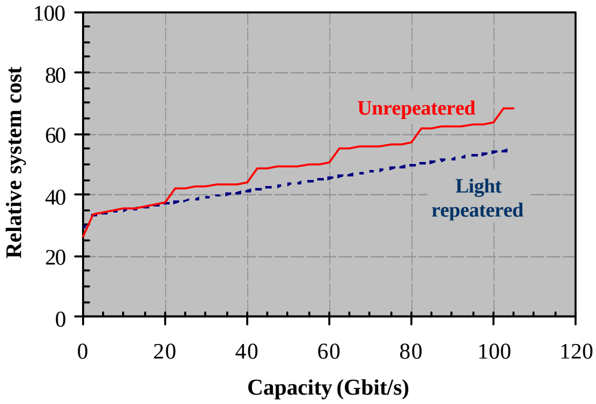


Figure 2: Relative system cost for a 2.5 Gbit/s line rate

Work Package	UR	LR
Wet Plant	Reference	+ 8 %
Marine Ops	Reference	=
Dry Plant @ 1*2.5 Gb/s	Reference	- 15 %
20 Gb/s upgrade	Reference	- 50 %

Table 2 : 2.5 Gb/s cost comparison per work package

The cost of adding 20 Gb/s is 50 % more costly with the UR since it means equipping an other fibre pair.

Work Package	UR	LR	TR
Wet Plant	Reference	+ 4 %	+ 50 %
Marine Ops	Reference	=	=
Dry Plant @ 1*10 Gb/s	Reference	- 10 %	+ 30 %
40 Gb/s upgrade	Reference	- 60 %	=

Table 3: 10 Gb/s cost comparison per work package

The cost of adding 40 Gb/s is 60 % more costly with the UR than with the LR since it means equipping an other fibre pair. The TR doesn't bode well with a low cost base.

2.2) Performance Comparison

The capacity and margin deltas will be presented as well as some key performance criteria (reliability, size, power).

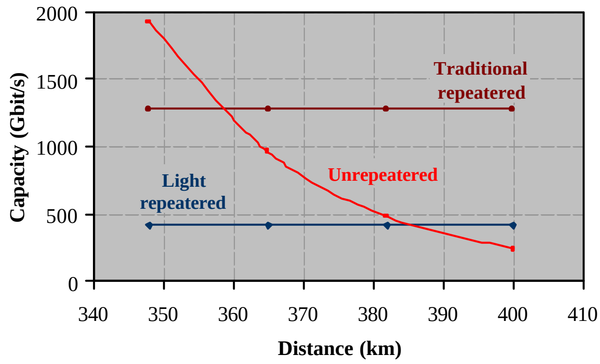


Figure 4: Capacity versus distance @ 10 Gb/s (constant margin)

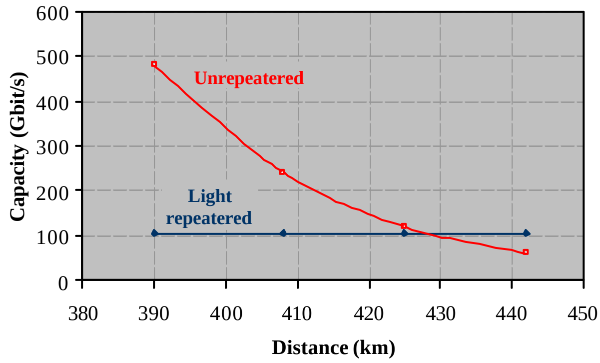


Figure 3: Capacity versus distance @ 2.5 Gb/s (constant margin)

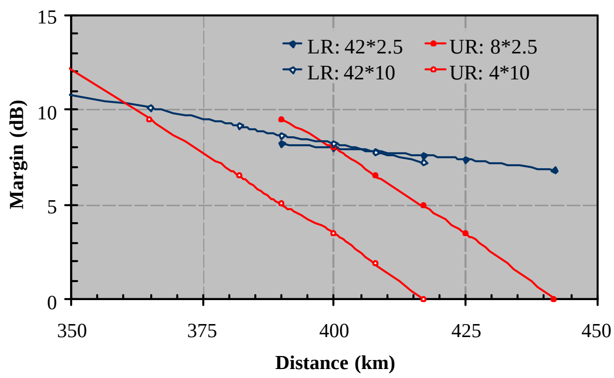


Figure 5: Margin versus distance (constant capacity)

System	Reliability	Outage	Power Consumption @ 100 Gb/s	Floor Space @100 Gb/s
LR	99,987 %	69 mn/year	8.8 kW	1.45 m^2
UR	99,978 %	116 mn/year	5.3 kW	1.6 m^2

Table 4: Top-level Performances

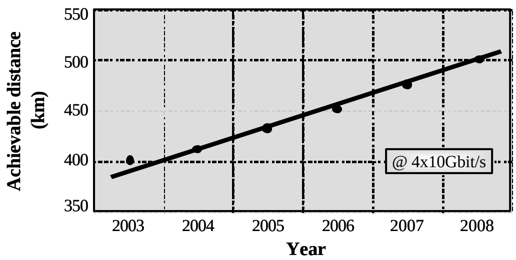
The configurations chosen shows perfectly well that the UR systems capacity and margin fall dramatically when one nears the limit of the UR technology (400 - 420 km) at which point the repeatered technology becomes operationally more attractive: similar SOL cost base, lower upgrade costs, same or higher capacity, higher reliability, rerouting flexibility with no margin impact. The LR is still more power hungry (+ 65 % @ 100 Gb/s) than the UR for a similar floor occupation (- 10 % @ 100 Gb/s).

3. UNREPEATERED SYSTEMS ROADMAP

For a given capacity, the reach of long unrepeatered systems is driven by the characteristics of the cabled fibre (attenuation, effective area, chromatic dispersion), of the line terminal (sensitivity, output power) and of the remote amplifier (gain, noise figure).

Cable: The current loss of pure silica core fibre fares at 0.165 - 0.170 dB/km but values as low as 0.155 - 0.160 dB/km could be expected through continuous design and manufacturing process improvements. On the other end, the fibre effective area will grow from 110µm^2, currently deployed, to 200µm^2 as it has been already demonstrated in the laboratory [7].

Line terminal: The sensitivity of the line terminal mainly depends on the quality of optical interfaces, i.e. transmitters, receivers and optical amplifiers, but it also depends on the modulation format and the type of FEC implemented. Starting from the current standards (NRZ-ASK, Reed-Solomon FEC) continuous performance improvements are expected from DPSK based modulation formats and concatenated or soft decision correction codes. In parallel, the availability of high power 980 nm pumps will allow to reduce the optical amplifiers noise figure and to increase the output power of both the signal booster and of the ROPA pump. Technology improvements are also expected in the chromatic dispersion compensation area, both from lower insertion loss in the compensating modules and from higher resilience to non-linear effects.



Area of improvement	2003	2004	2005	2006	2007	2008
Fibre loss (dB/km)	0.180	0.175	0.170		0.165	0.160
Fibre area (µm^2)	110			150		200
Modulation format	NRZ			DPSK		
FEC	Super FEC		Advanced super FEC		Soft decision	
High power booster (dBm)	30			33		
High power pump	Standard			High order		
Dispersion compensation	Standard		Low loss			
Remote amplifier	Standard		Advanced			

Figure 6: Unrepeatered Technology Roadmap

Remote amplifiers: The budget improvement brought by remote amplifiers can be further increased with second or third order pumping schemes [1]. Additional benefit can be sought from novel ROPA architectures, mixing post- and pre-amplification in the same housing.

Most of these improvements are intertwined which turns the system analysis into a complex exercise; as an example, high power units usability call for availability of large effective area fibres. Figure 6 shows how the tentative combination of all these technological and system design improvements will drive the achievable span for a 10 Gb/s WDM unrepeatered system. It demonstrates that the reachable distance could be increased by as much as 25% within the next five years, thus offering the capability to break the 500 km barrier.

4. CONCLUSION

A repeatered based solution can be a sound alternative to the unrepeatered technology for distances as short as 400 km when the hardware implementation is that of a “Light Repeater”: 2 pump Red band repeaters, 3 kV insulated cable and a standard terrestrial terminal. It can provide at least the same capacity (105 Gb/s to 420 Gb/s per fp @ 2.5 and 10 Gb/s respectively) with a similar SOL cost base. The upgrade costs are significantly more attractive and the system reliability is slightly better. Moreover the LR margin is sufficient and constant over the 380 – 420 km range, providing a lot of flexibility at the project implementation phase and making for easier risk management. Thus the LR could arguably be considered for some customers as the best value for money for a sub sea system in the 400 km range.

References

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