Cost allocation on a shared fiber pair using ROADM BUs

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Abstract: The purpose of this paper is to present a cost model for sharing spectrum across a fiber pair on a subsea system equipped with ROADM BUs and using *nm.km* as cost unit.

1. NEW SYSTEM DESIGN CAPACITY

Total transmission capacity over a single fiber pair on subsea systems has seen tremendous increases, a result of recent tremendous increase of the wet plant line bandwidth such as C^+ or C^++L, large increase in transmission rate with the introduction 8QAM and higher constellation scheme.

The table below represents system's achievable capacities while considering repeater bandwidth and channel spacing.

Waves spacing GHz/s	Spectral Efficiency b/s/Hz	Fp capacity Tb/s vs Repeater amplier bandwidth 36nm	41nm	55nm
33	4.5	20.8	23.7	31.7
37.5	4.0	18.0	20.5	27.5
40	3.8	16.9	19.2	25.8
50	3.0	13.5	15.4	20.6

Table 1: Fiber pair capacity for 150Gb/s waves

This tremendous transmission capacity over a single fiber pair becomes attractive for non-OTTs whose capacity needs could be accommodated by using a fraction of a fiber pair representing fewer terabits. Sharing a fiber pair ("fp") presents also the following advantages:

- Reduces the number of fp
- Reduces the project cost
- Reduces the sharing parties' investment
- Reduces the number of marine repairs having lower FIT repeaters.

Furthermore, sharing spectrum on a fiber pair allows each sharing party to benefit from technological advances and to increase maximum capacity independently from other parties. Management of each sharing party's wavelengths and power on the shared fiber must however be carefully engineered.

2. PARTY COST ALLOCATION

Historically, cost allocation on a multiple party system were based on Minimum Investment Unit (MIU) which consisted in an agreed upon low order capacity rate on a Digital Line Section (DLS). Nowadays, cost allocation for subsea infrastructures is rather prorated between the parties based on each party ownership in term of fiber pairs. For example, a four fiber pair system owned by four parties could simply have its construction cost divided equally between each party.

As an example, the graph below represents the investment cost and capacity for 4 parties - a, b, c, d - with four system designs serving the same end points.

The first is a 4 fp system costing $240M with one fiber pair dedicated to each party. The second is a 3 fiber pair system at $220M with 2 fp dedicated and 1 fp shared between two parties. The third one costs $200M, it is a 2 fp system with one dedicated fp and one shared fp between 3 parties. Finally, the fourth one is the same 2 fp system at $200M and each fp is shared between two parties.

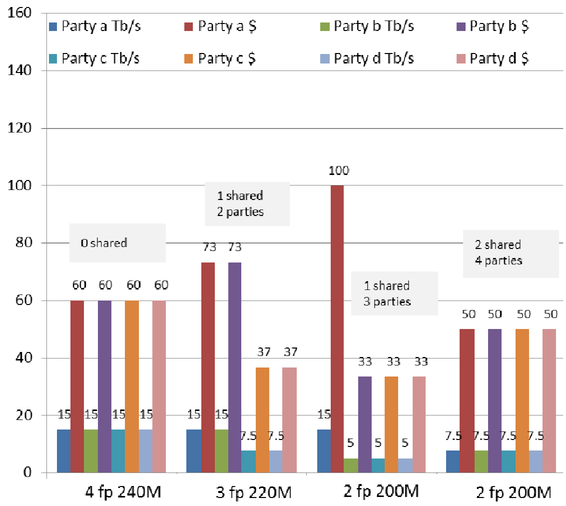

Figure 1: Party cost sharing comparison vs number of fp and shared fp.

The advantage of sharing fp is to reduce the project cost. However, as it can be observed in figure 1, a mix of dedicated and shared fp represents a financial burden to the dedicated fp party.

When funding is of the essence for a project and several smaller carrier and operators with less capacity need than very larger carrier or Web-scale/OOTs join together to build a subsea system, sharing all fiber pairs is a viable alternative.

3. SHARING SPECTRUM

Sharing spectrum on a point to point system is simple. Each party cost can be determined by prorating the fiber pair cost to the amount of spectrum ownership over the total amount of available spectrum.

On the other hand, sharing spectrum on a system with branches and ROADM BU requires particular attention.

For example, complexity arises when a party capacity need is only between a branch and one end of the trunk, or between two branches. Could the "un-used" part of the spectrum between the particular branch and the opposite end of the spectrum be attributed to another party and for what price? Or should this become common reserved spectrum for which cost will be equally charge to each party. How much is the value of this unused spectrum?

What is the value of guard bands required for ROADM BU filters?

What is the value of the trunk fiber spectrum freed when a ROADM filter is set to a lower value than its maximum setting?

To answer these questions and determine the cost allocated to each party sharing a fp, we propose a costing model based on Shared Spectrum Unit (SSU) defined as "nm.km".

The number of SSU used by a party multiplied by the value of an SSU will govern each party cost allocation.

4. SSU UNIT AND VALUE

To calculate the number of SSUs in a system and its unitary value, we will use one of the example presented in section 2: a two fp system with four parties. One fp is dedicated to a single party and the second fp is shared among 3 parties.

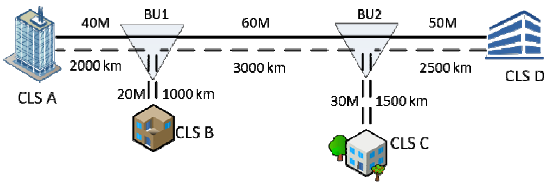

Figure 2: System example

The system technical characteristics are as follow:

Wet plant:

- 32nm spectrum bandwidth
- designed to support a power budget at 15 Tb/s

Terminals used for initial design:

- 8 QAM waves spaced at 40 GHz spacing on all DLSs
- Total trunk fiber capacity = 150Gb/s * 32 nm / 0.32 nm = 15 Tb/s

The number of SSUs is calculated on the trunk fiber only (the branch being a point to point system BU – CLS, its cost allocation can simply be prorated to the spectrum usage per party).

In our example, the trunk length is 7,500km and the spectrum is 32nm. If we represent this in two dimensions, it will form an area of 32nm x 7,500 km = 240 000 nm.km . Next is to determine SSU value.

From figure 2, the trunk cable cost is $150M; cost portion of 1 fp is therefore $75M. The value of a SSU is $75M / 240,000 SSU units = $312.50

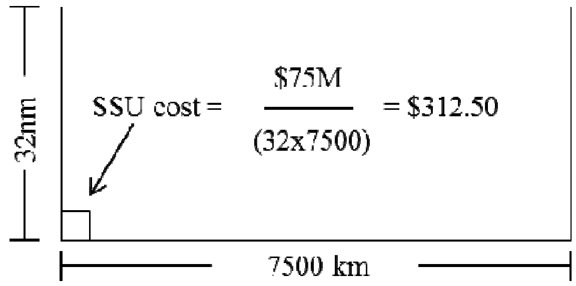

Figure 3: SSU value.

5. SHARED FP SPECTRUM ALLOCATION

The next step consists in defining all possible connections between terminals, spectrum wise. Figure 4 illustrates our system where we find 4 complete spectrum links (green, blue, yellow, red) and 8 sub-links. Table 2 list all possible links and sub-links.

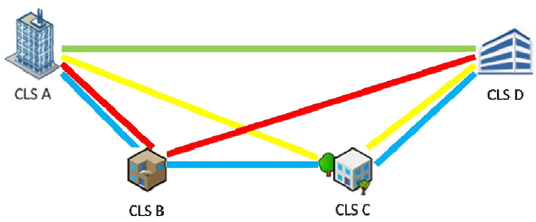

Figure 4: Connectivities between landings.

Link	Sub-Link	Length on Trunk (km)
A-D	A - D	7500
A-B-D	A - B	2000
	B - D	5500
A-C-D	A - C	5000
	C - D	2500
A-B-C-D	A - B	2000
	B - C	3000
	C - D	2500

Table 2: Links Listings.

Parties then have to list their maximum amount of capacity needed on each sub-link while respecting the following rule:

1. Each sub-link of a parent link has to have the same spectrum width (and capacity for the initial design).
2. The sum of all sub-links SSUs must be less or equal to 240,000 (if less, the unaccounted for SSUs become common reserved spectrum for which cost is allocated among the parties).

The spectrum division in sub-links is illustrated below:

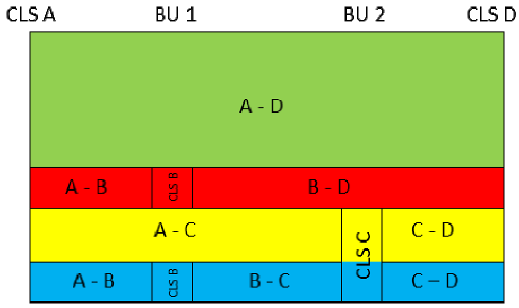

Figure 5: Sub-links representation between landings

An example of established maximum capacity needs (in Tb/s) for each 4 parties is represented below:

Capacity In Tb/s per Party per sub-link					
Link	sub-link	a	b	c	d
A – D	A - D	3.00	3.45	3.00	2.55
A – B - D	A - B	0.00	0.60	0.30	0.00
	B - D	0.00	0.00	0.00	0.90
A – C - D	A - C	0.30	0.00	0.00	0.00
	C - D	0.30	0.00	0.00	0.00
A – B - D	A - B	0.00	1.28	0.64	0.00
	B - D	0.00	0.00	0.00	1.92
A – C - D	A - C	0.64	0.00	0.00	0.00
	C - D	0.64	0.00	0.00	0.00
A – B – C - D	A - B	0.00	0.96	0.96	1.92
	B - C	0.00	0.96	0.96	1.92
	C - D	0.00	0.96	0.96	1.92

Table 3: Capacity for each Party per sub-link in Tb/s.

The capacity needs in table 3 fulfill the shared fp spectrum by respecting the two rules: each sub-link part of a parent link has the same spectral width and the sum of all sub-links represents 240,000 SSUs. This is represented in the two tables below:

Sprectrum (nm)						
Link	Sub-link	a	b	c	d	Total
A – D	A - D	6.40	7.36	6.40	5.44	25.60
A – B - D	A - B	0.00	1.28	0.64	0.00	1.92
	B - D	0.00	0.00	0.00	1.92	1.92
A – C - D	A - C	0.64	0.00	0.00	0.00	0.64
	C - D	0.64	0.00	0.00	0.00	0.64
A – B – C - D	A - B	0.00	0.96	0.96	1.92	3.84
	B - C	0.00	0.96	0.96	1.92	3.84
	C - D	0.00	0.96	0.96	1.92	3.84

Table 3: Spectrum allocation per sub-link.

Qty of SSU per Party per sub-link						
Link	Sub-link	a	b	c	d	Total
A – D	A - D	48000	55200	48000	40800	192000
A – B - D	A - B	0	2560	1280	0	3840
	B - D	0	0	0	10560	10560
A – C - D	A - C	3200	0	0	0	3200
	C - D	1600	0	0	0	1600
A – B – C - D	A - B	0	1920	1920	3840	7680
	B - C	0	2880	2880	5760	11520
	C - D	0	2400	2400	4800	9600
	Total:	52800	64960	56480	65760	**240000**

Table 4: Total number of SSUs per party and sub-link.

Notice that the quantity of SSUs for sub-links having the same spectral width is not equal which captures the physical distance variation per sub-link of a same parent link.

The respect of the spectrum width is also verified by adding the sub-links spectrum width for each sub-segment on the trunk fiber:

CLSA-BU1		BU1-BU2		BU2-CLSD	
A - D	25.60	A - D	25.60	A - D	25.60
A - B	1.92	B - D	1.92	B - D	1.92
A - C	0.64	A - C	0.64	A - C	0.64
A - B	3.84	B - C	3.84	B - C	3.84
Total:	32.00		32.00		32.00

Table 4: Total spectral usage on trunk fiber per sub-segment.

Having established the value of an SSU at $312.50 in section 5, each Party cost allocation for spectrum usage is therefore:

Party a	Party b	Party c	Party d	Total
$17M	$20M	$18M	$21M	$75M

Table 5: Shared fp cost allocation per Party.

6. OTHER CONSIDERATIONS

Guard bands will also be required due to the use of filters at the R-OADM BUs which will reduce the amount of available spectrum. This has not been factored in this exercise for simplicity.
Cost allocation for other elements of the systems such as branches, CLS, terminal equipment would be added to each Party based on the C&MA rules.
Filter size of ROADM BU can be adjusted to lower value than what is presented in this article which would increase the end to end link A – D capacity.

7. CONCLUSION

Sharing a fiber pair among carriers becomes a valid alternative assuming that each Party capacity needs is met by a shared fp design.
This article specifically presented a method to accurately allocate spectrum cost to each Party on a shared fiber pair in a particular system where ROADM BUs are in used.