Tightrope walking, or how Sea-Me-We 3 was upgraded to 10 Gbit/s and keeps being upgraded.

Jean-Baptiste Thomine – Sea-Me-We 3 CWG* Co-Chair (AXIOM SAS)
Email: jean-baptiste.thomine@axiom.fr
*CWG = Commissioning Working Group.

Abstract: Sea-Me-We 3 was originally designed as a 8 x 2.5 Gbit/s per fiber pair WDM system. It is today a full-fledged 10 Gbit/s system carrying over 18 10Gbit/s wavelengths per fiber pair on some segments. This obviously meant pushing the envelope since there was no contractual requirement for Sea-Me-We 3 to offer any upgradability to 10 Gbit/s. Multiple in-service upgrading of the longest submarine cable system in the world was a challenging process that Sea-Me-We 3 Purchasers and their suppliers successfully performed five times in a row. This article offers a look at the history and methodology used, to share the experience gained on Sea-Me-We 3 upgrades over the last decade.

1. SEA-ME-WE 3 System and Upgrades

The Sea-Me-We 3 Cable System design was conceived from 1995 to 1997. Building started early 1997 and was completed in 1999, for an initial capacity of 4 x 2.5Gbit/s (wet plant design 8 x 2.5Gbit/s). To this day, Sea-Me-We 3 remains both a precursor and a record-award cable in many senses:

- Sheer size: Sea-Me-We 3 cable is over 39,000km through ten segments spanning from Western Europe to Far East Asia with a "side" segment connecting to Australia.
- Connectivity and number of players: Sea-Me-We 3 has 39 landing stations, lands in 33 countries and is owned by more than 80 carriers . In order to try and keep the implementation Plan Of Work (18 months planned, 24 months achieved), the System construction was contracted to a mix of all the suppliers qualified at that time (5 suppliers).
- Technology: Sea-Me-We 3 was one of the two first systems designed to use the optically amplified WDM technology (N x 2.5Gbit/s at that time) and was also, until recently, the only system (with S3WS/SAFE) using the OADM underwater technology.

The system is so large and offers so much worldwide connectivity to its users that since it has been in service in 1999, it has never stopped filling up with traffic and there was never a year where the owners and the technical team in charge of the project did not investigate further upgrade conditions and capabilities. Sea-Me-We 3 has been upgraded 5 times so far, generating a lot of experience in upgrading methodology, which the author wants to share in this paper.

2. EARLY UPGRADES

2.1. Design capacity upgrade

The initial System was hardly deployed when the owners decided in 1999 to launch an upgrade at the full design capacity (8 x 2.5Gbit/s). This was a "classical" upgrade (within design limits), however the Sea-Me-We-3 technical group (CWG) started to push the suppliers into interesting new directions, because the system was already quite filled up in terms of traffic, which generated constraints in terms of traffic management:

- While suppliers were looking at that time to have the system shut down and dedicated to upgrade fine-tuning during periods of weeks (i.e. traffic down for weeks...), they were pushed by the

CWG to devise methods to insert additional waves in live traffic conditions...and this was more or less the first time in the world that in service upgrades were performed.

- In some specific cases, in service upgrade was not technically feasible, and specific traffic switching methods were designed to move traffic to other routes...and this was the first time MOPs (Methods Of Procedures) for upgrading while minimising traffic impact on the system were developed.

2.2. First Upgrade over design capacity

At the time of Sea-Me-We 3 initial commissioning (1999), it was noted by Sea-Me-We 3 CWG that the actual optical margins were far in excess of what was necessary to carry the 8 x 2.5Gbit/s design capacity and it was suggested to the owners of the system that Sea-Me-We 3 might be able to carry 10Gbit/s technology. The owners were indeed very interested and "over design capacity" field trials (again a first in the first world) were performed by the suppliers, and proved successful. So much so that in late 2001, the first 10Gbit/s upgrade started and was successfully completed in early 2003. This was again a time of learning lessons:

- More sophisticated MOPs were developed (in view of the growing traffic and stricter requirements of users re-traffic management),
- Management of the older Sea-Me-We 3 SDH layer during upgrades: re-connecting existing SDH (and traffic) to new SDH equipment deployed to accommodate the new 10Gbit/s technology.

Again, upon commissioning, and despite having doubled the capacity over the design, it was noted that significant additional optical margins remained....leaving open the technical doors to further upgrades.

3. SERIOUS UPGRADE BUSINESS 2005-2011

3.1. End of internet crisis, improved technology

Upon completion of the first 10Gbit/s upgrade, there was a bit of a stop in upgrading due to the 2001-2004 internet crisis.
Meanwhile, enhanced technologies had been developed by the suppliers including better terminal equipment chips (modulation and receive side) and much improved Forward Error Correction capabilities providing extra margins.
Sea-Me-We 3 Upgrade business thus re-started early 2005 at the same time Sea-Me-We 4 was being deployed.

3.2. Second Sea-Me-We 3 10G Upgrade

The second Sea-Me-We 3 Upgrade was designed in a period where the constraints on upgrade had significantly increased compared to the early 2000:

- The system was nearly 100% filled up with traffic, leaving little room for easily diverting traffic in system
- The users constraints re-traffic management had increased very significantly: KPI with final customers were now a standard, requirement for advance notice for any operation, strong preference for traffic routing to take place over week-ends, etc...

Moreover the target of this upgrade was a huge increase in the capacity, by a factor 4 to 5 on some connections, and required quite significant changes to the network architecture (especially SDH), with associated traffic interruptions or risks thereof.

This was a time where Sea-Me-We 3 CWG had to completely re-build its upgrade methodology and to create (nearly from

scratch) very professional upgrade procedures involving:

- Pre-planning in cooperation with the Sea-Me-We 3 NOC and Network Administrator to find out and define phases and operational steps.
- Drafting of very detailed MOPs including pre-requisites to carry operations, matrix of responsibilities, stepping, including connection details, roll back plans etc...
- Familiarising suppliers with prioritising traffic over any of other constraints (like shipping, personnel management, etc...)
- Coordinating with cable stations to ensure full understanding of the procedures and schedule, etc.

This was indeed a period of great work and creativity where many upgrade management concepts were devised and proof-tested.

3.3. Third and Fourth Sea-Me-We 3 10G Upgrades

The third and fourth Sea-Me-We 3 upgrades were follow-ups of the second Sea-Me-We 3 Upgrade, benefitting from the ever-improving Terminal Equipment performances improvements:

- Better understanding of the actual margins associated to the terminal equipment, leading to less conservative and more "reality-aligned" power budgets.
- Technology improvement; use of DPSK modulation format on the longest Sea-Me-We 3 segments to improve the performance budgets.

Those upgrades were implemented using similar management guidelines as in the Second 10G Upgrade, and more and more technical tricks to try and minimise traffic impacts as traffic was growing. It is to be noted that upon the completion of the 4th 10G upgrade in 2010, some of the Sea-Me-We 3 segments had reached an actual capacity of 13 times the initial design capacity stated in 1997 !

4. OVERVIEW OF UPGRADE MANAGEMENT

This section presents an overview of the upgrade management principles, tricks and issues as could be gained from the experience described above.

4.1. Upgrade Contract

It is of benefit to make the suppliers aware very early of the constraints associated with an upgrade...and very early means telling them the truth at the contract negotiation stage and having commitments written in the upgrade contract, such as:

- Agreement to stage traffic affecting works at any time decided by the Purchasers (inc. Week-end at night, etc...)
- Agreement to re-stage upgrade activities at a time agreed by the Purchasers if the previous timing was planning traffic affecting activities at a time not convenient (such as Olympic games, football worldcup, etc...)
- Agreement to stage capacity upgrade in as many steps as necessary to minimize traffic impacts to the Purchasers
- Buffer period in the upgrade POW to account for unexpected events (such as cable faults).

4.2. Very early planning

In-service upgrade means that existing traffic carrying capabilities have to be sustained up to the time when upgrade traffic carrying capabilities are deployed and traffic is switched over to the new

equipment. As such, there is a need to ensure that there are enough equipment-maintaining capabilities in stations to maintain at the same time the new equipment and the equipment to be replaced. This has an important consequence that stations capabilities to carry equipment (floorspace, electrical power, aircon) have to be sufficient to carry for a while both older and new equipment. In Sea-Me-We 3, this has led sometimes to specific operations whereas older partly unused equipment was made free of traffic, to be decommissioned in advance of an upgrade, so as to make physical room available for the new equipment. Analysis and mitigation of station capabilities to carry Upgrade is a very early planning activity, due to the time it takes to free equipment of traffic and to improve stations accommodating capabilities in terms of power plant, etc...

4.3. Early planning

This part of the upgrade planning is probably the most enjoyable and brain-racking part. This is the time when the technical project team (CWG) and traffic parties meet and discuss and brainstorm to determine what are the most optimised upgrade steps to minimize impact on traffic. On a complex system like Sea-Me-We 3, the optimisation exercise tastes very much like a huge Sudoku game...anyway, smart or smarter (or dumb...), the output is a PLAN with sequences which the technical project management team (CWG for Sea-Me-We 3) translates into detailed procedures.

4.4. MOPs drafting

MOPs drafting consists in translating the PLAN above into detailed procedures including:

- List of actors involved in the work (and their contact points)
- Prerequisites for starting the work
- Detailed time schedule (down to the hour level of detail for some activities)
- A comprehensive list of traffic cut and the extent of the cut, traffic risk activities
- Step by step description of the activities including who is responsible for what
- Roll back plan in case something goes wrong
- Technical attachments providing details of how the work is done, connection references, diagrams, etc...

  The MOP provides a detailed guideline which then needs to be presented to all parties involved, modified as adequate then endorsed by all (i.e. NOC, suppliers, stations, etc...).

4.5. Full dedication

As good as the PLAN and MOPs may be, when the operation is complex enough (as in Sea-Me-We 3), personnel in charge of the operation should forget that there are night times and week-ends and vacations, because one part of the MOP or another will always go partly wrong and there will be a need to decide on the spot what to do after it has gone wrong....obviously, because of traffic maintenance windows and of Murphy's law, things go generally wrong at late hours on week-ends....

4.6. Team work

The persons in charge of managing the upgrade have to understand that a successful upgrade can only be achieved through team work. Good friendship and cooperation with the other upgrade actors is mandatory, especially with:

- NOC: NOC is in charge of managing the cable network 24/7 and its help is

invaluable, so it is absolutely mandatory to ensure NOC has endorsed all upgrade steps and has a full knowledge of such.

- Station staff: station staff will perform the traffic rerouting work on-site as well as supervise the supplier(s) work, and their understanding of the activity and cooperation is mandatory as well.
- Upgrade supplier(s): the relation with the upgrade supplier(s) shall not be contractual only and there is a need for a mutual understanding as to what is expected in terms of traffic impact and traffic impact mitigation. The author found that suppliers do not generally have a solid "built-in" feeling of traffic requirements (they are not carriers after all!). However suppliers can learn quickly and do an excellent work when motivated appropriately...
- Cable system management: it helps to have a cable system management trusting its technical team, i.e. a top management giving full responsibility to the technical team during upgrades. In this regard, Sea-Me-We 3 top management is outstanding in that it has always left the Sea-Me-We 3 technical team (CWG and traffic experts) take full responsibility for upgrade operational matters.

4.7. Upgrade "standard" traps

The following provides a (non-exhaustive) list of traps and other (not so major) issues encountered during an upgrade:

- Schedule is already noticed to capacity users and supplier has forgotten to ship a mandatory item on-site (or it did not clear custom): this does not look too good because the schedule is noticed, and one has to look for a work-around.
- National holidays and special events: one of the capacity users has forgotten to advise in advance that a planned traffic operation will take place during a high-importance national event: need to re-schedule the traffic operation. Usually not a huge issue as all parties involved understand that this could happen to anyone.
- Cable fault: a wet cable fault messes up the upgrade schedule. If properly managed contractually, this will not be a big issue again. Capacity users understand cable faults and that they cannot be planned.
- Cable fault on another system: this is a more vicious variant of the previous point. Some of the users suffer from a cable fault on another system and the other system uses the System under upgrade as restoration. They then try to push to re-schedule the traffic-impacting activities associated to the upgrade. This type of situation is more difficult to manage and can lead to "lively" discussions between the parties involved.

4.8. Major Upgrade issues and mitigation

While 4.7 is discussing undesirable situations which affect upgrade implementation locally (i.e. in a small scale), this chapter deals with major issues which can turn into real nightmare, some examples as follows:

- Unreliable equipment introduced in the network: due to upgrade momentum and traffic requirements, the upgrade equipment is generally carrying traffic before being fully commissioned. It can happen that such new equipment actually shows a reliability problem and starts failing significantly shortly after it is deployed and carrying traffic. This can affect a large part of the network.

- Equipment with software bug introduced in the network: the new equipment deployed on the network shows to be "software unstable" after a while.
- Firmware upgrade: in some specific upgrade circumstances, the existing equipment will require a firmware upgrade to accommodate new technology. Anyone having already upgraded his smartphone understands quickly how dangerous this type of operation can be !

Issues like described above can never be 100% avoided. They can however be strongly mitigated by:

- Having the suppliers demonstrate in advance through tests carried in their labs that the equipment is stable. Firmware upgrades shall also be demonstrated in labs, on configurations sufficiently similar to the planned configuration.
- Apply Technical "robustness" filters on the equipment before it actually carries traffic: exhaustive factory testing, including temperature burn-in, leaving the equipment running in station as long as possible before traffic is introduced on it.
- Protect your traffic as soon as possible: once a new equipment is carrying traffic, protection against the equipment failure should be introduced ASAP (for example, 1+1 protection, N+1 protection, SNCP protection, etc...).
- Stop operations IMMEDIATELY if some issue starts to materialise, to avoid contamination at the network level....
- Keep original traffic-carrying equipment alive for a while as a backup.

5. FUTURE PROSPECTS

After 5 previous upgrades (including 4 over the initial design capacity), Sea-Me-We 3 is now seriously investigating further upgrades using the new coherent technologies at 40Gbit/s and 100Gbit/s. Those technologies provide transmission performances significant improvements that are assessed to be sufficient to counter-balance the decrease of margins associated to a further capacity increase:

- Coherent technology with phase modulation provides a 2dB to 3dB improvement with regards to previous modulation formats
- The new transponders are equipped with new FEC with performances very much improved compared to previous generations, leading to an expected 2dB to 3dB improvement again.

Using those new technologies, it is assessed that Sea-Me-We 3 capacity could typically be increased, again!, by a factor 3 to 4 compared to the current situation.

6. ACKNOWLEDGMENT

Upgrading huge systems like Sea-Me-We 3 is a team work and the author dedicates this paper to all Sea-Me-We 3 partners actively involved in the making up of the Sea-Me-We 3 upgrades, including: Sea-Me-We 3 Singtel NOC, Sea-Me-We 3 CWG members (and especially the author co-chairs from BT, CT and TM), Sea-Me-We 3 Procurement Group and Management Committee, all Sea-Me-We 3 station personnel (from 35 carriers) involved in the work on site, and all the suppliers which have been in charge of deploying the various upgrades.