ENHANCED NETWORK TOPOLOGY FOR IMPROVED SYSTEM AVAILABILITY

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Abstract: The reliability metric of availability of undersea communications systems is typically only applied to terminal equipment, because the long Mean-Time-to-Repair of submerged plant would dominate the metric. In theory, it can encompass the effect of all failures, and in fact, availability is more appropriate than "ship repairs" to explore quantitatively various fault scenarios in the submerged plant.

This paper analyzes the effect of external aggression faults on a set of alternate network topologies designed to increase overall system availability. These topologies include redundant paths across high hazard areas, both undersea and terrestrial. Several system scenarios will be presented along with the resulting improvements to availability.

1. INTRODUCTION

Reliability metrics for undersea communication systems have historically been separated into two parts: ship repairs due to intrinsic equipment faults is the metric applied to the submerged equipment; availability of a channel is the metric applied to terminal equipment. This division is warranted because of the large difference in the mean-time-to-repair of the two types of outages.

Faults caused by external aggression of all types are not included in either metric.

Owners are, of course, concerned with the availability of the entire network and, in principle, availability could encompass the effect of all failures. In this paper, we examine the contribution of failures in the submerged plant on the availability of a system. Specifically we will include the effects of external aggression because these events are geographically dependent on the cable route, and water depth of the route and thus represent a contribution to availability that is relatively independent of the total length of the system. Several network topologies are analyzed to determine if the availability can be improved with minimal impact on cost.

2. BASELINE AVAILABILITY

We use the textbook definition [1] of availability (A):

$$A = \frac{MTTF}{MTTF + MTTR}, \qquad (1)$$

where $MTTF$ is the Mean Time to Failure and $MTTR$ is the Mean Time to

Repair. Assuming a constant hazard of failure, the *MTTF* is simply the inverse of the Probability of Failure (λ).

The unavailability is the complement of availability. Outage (*O*) is found by converting unavailability into a useful rate.

$$O = (1 - A) * 8766 * 60 \text{ min/yr.} \quad (2)$$

Availability and unavailability have the same mathematical properties as Reliability and Probability of Failure. Hence, the same combinatorial relationships can be exploited. For a system where the transmitted signal traverses a series of components that are linked with optical fiber, the final availability is the product of all individual availabilities.

$$A_{series} = A_{Component1} * A_{Component2} \cdots \quad (3)$$

Also of interest is the case of parallel paths (redundancy via 1+1 protection). The final availability in this case can be found from:

$$A_{parallel} = 1 - (1 - A_{Path1}) * (1 - A_{Path2}) \,. \quad (4)$$

Note that the right-hand-side of Equation (4) is a rearrangement of the first two terms of the Binomial Distribution for n=2. The 1+1 protected system will be available when both paths are available and when either path has failed.

(a) Availability Assumptions for Terrestrial Equipment

The availability requirements for terrestrial cable station equipment are well defined for each system. We assume that the SDH and LTE have sufficient redundancy, using for example 1:N protection, so that the availability of terrestrial equipment is 2 – 3 orders of magnitude better than the availability of submerged equipment and so can be ignored (availability > 99.999% or unavailability on the order of 10^{-5}).

Power Feed Equipment is deployed with sub-system redundancy so that availability of a single PFE is in line with the order of magnitude assumption with respect to the submerged equipment. In addition, there are system-level redundancies in the PFE deployment that significantly reduce the end-to-end contribution of the PFE to the outage of the system. One such redundancy is the ability of one PFE to supply power for the entire length of the system trunk (single-end feed). The response of a PFE in such a situation occurs within seconds, leading to an end-to-end contribution of the PFEs to unavailability on the order of 10^{-7}.

(b) Availability Assumptions for Intrinsic Faults in Submerged Equipment

Intrinsic faults are those caused by failure of the as-manufactured equipment. Due to the extraordinary diligence of submarine cable suppliers, these types of failures in the submerged plant of steady-state active systems are rare.

Analysis of cable fault data [2, 3, 4] indicates consistently that failures due to components account for less than 10% of all cable faults. We will assume, then, that the contribution of intrinsic failure to the availability of the submerged plant is 1 to 2 orders of magnitude better than the availability found from considering extrinsic faults, depending on the relative lengths of shallow and deep water in the system.

3. CABLE FAULT DATA

The occurrence of extrinsic faults, those faults due to events outside the control of the manufacturer, has been analyzed on an on-going basis. In the last analysis [5], greater than 90% of faults with identified cause were due to external aggression. Within the category of external aggression, greater than 80% of faults were due to human activity, predominantly fishing, dropping and/or dragging anchor and dredging.

The rate of occurrence of extrinsic failures has a strong dependence on geography and geology. The rate of extrinsic failure in shallow water can exceed the rate in deep water by a factor of 10. The rate of faults for cable deployed in depths greater than 1000 m has been low and stable over the time period. In contrast, the rate of faults for cable deployed at depths less than 1000 m is historically higher, but has shown significant improvement over the time period.

In the following analysis, we will use the following fault rate values to explore the methodology.

- Shallow water: 0.2 faults per 1000 km per year
- Deep water: 0.02 faults per 1000 km per year.

4. NETWORK TOPOLOGY AND AVAILABILITY FROM EXTRINSIC CABLE FAILURES

Network designers have a choice of approaches to consider when connecting landings in an undersea system. Selecting the appropriate approach is based on a trade-off of fault resilience vs. network cost.

In the analysis, we will consider both trans-oceanic links and regional links with the following generic characteristics:

Table 1 Lengths of Cable for Example Submarine Networks

	Trans-Oceanic	Regional
Deep-Water km	4,600	1,500
Shallow Water	850	1,100

MTTR for a fault includes the following components:

- 1 day for mobilization;
- 1 – 6 day transit time of repair vessel, assuming a fault in the middle of the length under consideration and ship speed of 500 km/day;
- 5 days for repair.

(a) Point-to-Point System

The simplest and least expensive approach is a direct single segment between two landings. In this approach, no route redundancy is provided and protection against external aggression faults relies upon the route selection, armoring and burial of the cable in the hazardous regions. This approach may be acceptable if alternative networks are available for traffic restoration in the case of a fault.

Availability and outage can be calculated using the nominal values described above. For example, the expected number of faults (*flts*) per year in shallow water of the trans-oceanic system is:

$$0.2\, flts / 1000 km.yr * \frac{850km}{1000} = 0.17$$

The remaining calculation details follow:

$$MTTF = 8766 / 0.17 = 52{,}400hr$$
$$MTTR = 24 * (1 + 1 + 5) = 168hr$$
$$A_{shallow-transoc} = \frac{52400}{52400 + 168} = 0.9968$$
$$O_{shallow-transoc} = (1 - 0.9968) * 8766 = 28hr / yr$$

The results for the two considered point-to-point networks are:

Table 2 Availability and Outage for Point-to-Point System

Fault Type	Availability	Outage (min/yr)
TransOceanic Shallow Water	0.9968	1,700
TransOceanic Deep Water	0.9970	1,600
Regional Shallow Water	0.9958	2,200
Regional Deep Water	0.99918	430

It is interesting to note that shallow water faults and deep water faults due to external aggression contribute equally to outage for a trans-oceanic point-to-point system. In contrast, the outage due to shallow water faults in the generic regional system is 5 times greater than the outage due to deep water faults.

(b) Fully-Redundant Ring Network

Should fault resilience be the paramount concern, a fully redundant system can be utilized. Of course, this level of protection results in the most expensive network implementation. Costs of the submerged equipment are essentially doubled; costs of the terrestrial equipment are not quite doubled. The full ring requires an additional set of terrestrial equipment, but the ring architecture also fully protects this equipment so that 1:N protection schemes for the transmission equipment are not required. The additional cost of terrestrial equipment is offset by the cost of the protection equipment and the reduced complexity.

In this example, we assume that the lengths of the ends of the redundant segments of the ring terminate in the same cable stations and the lengths of the two segments are essentially the same. Using Eq. (3) and the results of the previous section, the availability of a segment can be found.

$$A_{transoc} = A_{shallow-transoc} * A_{deep-transoc}$$
$$= 0.9938$$
$$A_{regional} = 0.9952$$

Now, using Eq. (4), the improved availability due to the full 1+1 protection can be found. These results are summarized below.

Table 3 Availability and Outage for Full Ring Network

System Type	Availability	Outage (min/yr)
TransOceanic	0.999962	20
Regional	0.999975	13

As expected, the availability is improved by 2 orders of magnitude.

(c) Alternate Network Topology

A balanced approach between these two options is shown in Figure 1. This hybrid ring architecture provides redundancy only where it could be most effective, namely at the high hazard areas in the shallow water routes to the cable stations. Considerable savings are achieved by avoiding a second expensive deep water route.

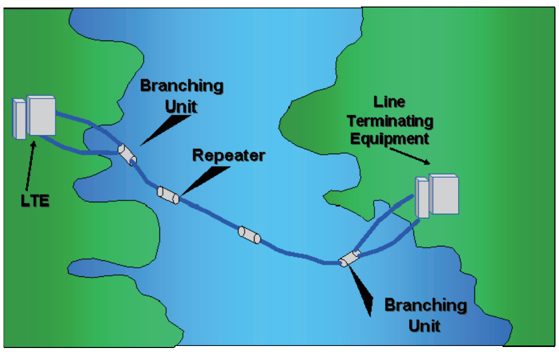

Figure 1 Alternate Network Topology

We assume that the Branching Units are moved to the edge of the shallow water regions. In this case, the availability of the redundant shallow regions is found using Eq. (4); the total availability for the network is found by combining this with the availability of the deep water section using Eq. (3). The contribution of shallow water faults to the availability and outage of the Network is shown in Table 4.

These outages must be added to the corresponding deep-water outages in Table 2 to get the total outage for the network. It can be seen that with this topology, the contribution of shallow water faults is greatly decreased. Since the shallow water and deep water extrinsic faults contributed equally to outage in the trans-oceanic point-to-point example, the alternate topology effectively halves the outage. For the regional network example, the outage decreased from a total of 2,630 min/yr to 440 min/yr, a factor of 6.

Table 4 Availability and Outage for Shallow Water Faults for Alternate Network

System Type	Availability	Outage (min/yr)
TransOceanic Shallow Water only	0.999990	5.4
TransOceanic Total	0.9970	1,600
Regional Shallow Water only	0.999982	9.2
Regional Total	0.99916	440

(d) Sensitivity to Parameters

The improvements in availability that can be expected from the suggested alternate topology depends upon the initial expected faults per year in shallow and deep water which in turn depend upon the assumed length of these sections and upon the assumed rate of external aggression failures. How do these availabilities change as the assumed faults per year change?

If a new external aggression failure rate per year is defined in terms of the one originally assumed herein as $\lambda_x \equiv x * \lambda_0$, then manipulation of the equations will show that any desired availability under this new assumption can be cast as:

$$A_x = \frac{1}{1 + \dfrac{MTTR * x}{MTTF_0}}$$

$$\approx 1 - \frac{MTTR * x}{MTTF_0} + \ldots$$

To first order, the outage for a new failure rate assumption is directly proportional to the outage found under the old assumption by the same factor. The error is less than 1% for up to an order of magnitude increase in failure rate.

Changes in length of the network under consideration affect both the *MTTF* and the *MTTR*. For shallow water, where the *MTTR* is dominated by the repair time, the outage of the longer shallow section is again proportional to the ratio of the length of the section to the baseline length. For the deep water section, where transit time to the site can be largest factor in the *MTTR*, the outage will scale as one-half the square of the length ratio, in the limit where the transit time greatly dominates the *MTTR* and the fault is mid-span.

These limiting cases will also be useful in considering the transit time of the repair ship from its home port, rather than using the simple assumption made here that the ship followed the cable route.

For regions of the world where the rate of external aggression faults are significantly higher than the global average, use of the alternate topology can greatly reduce outage for those cases where a ring is deployed.

For trans-oceanic systems, use of the alternate topology essentially reduces the outage to that caused by external aggression faults in deep water. If further improvements are required, the judicious application of light armor to the deep water cable, for example, SL17 Special Application (SPA) cable, can reduce the failure rate. To our knowledge, there has never been an external aggression failure of SPA cable in deep water; so a factor of 50 improvement can be conservatively applied. If both the alternate network topology and light-armor cable are used in the example transoceanic system, then the availability of the submerged network is better than 99.99%.

5. TERRESTRIAL DIVERSITY

As with the undersea segment, route diversity, can also be applied to the terrestrial route from the cable landing to the cable station to reduce the impact of external hazards. One approach to terrestrial diversity for the case of a point-to-point submerged system is shown in Figure 2. The system is powered from a small facility close to the landing while the optical path is extended inland to the cable station.

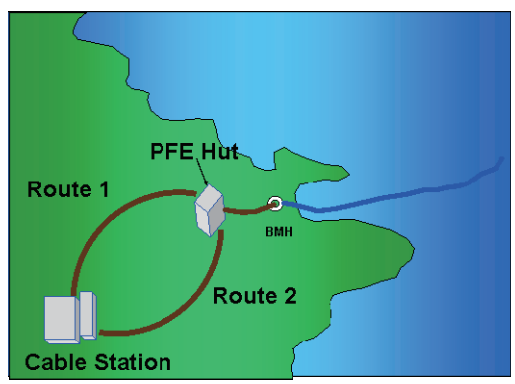

Figure 2 Diverse Terrestrial Route

For this configuration, automatic switching can be implemented to detect a fault and switch routes in a time frame that greatly improves on the *MTTR* for a single fault along the terrestrial route.

As was the case for undersea route redundancy, terrestrial route redundancy also improves the overall availability of the terrestrial route several orders of magnitude. It provides a useful and cost effective approach for network designers looking to maximize network availability while maintaining a practical level of investment. [6]

6. CONCLUSIONS

It can be seen that the simplest and least expensive system topology suffers from serious outage which is unacceptable from a network point of view. The full ring offers dramatic improvement, at an associated increased cost. The topology which offers redundant shore ends, where cable is most at-risk to external aggression presents an attractive alternative for balancing network availability and cost. Since shallow water fault rates are highly dependent on specific cable routes, the results of this analysis need to be confirmed on a system by system basis. Finally the use of redundant terrestrial routes is essential for any long backhaul link.

7. REFERENCES

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