ATIS STANDARD

ATIS-0100031

A METHOD TO DISPLAY METRICS RELATED TO THE ROBUSTNESS OF THE UNDERSEA CABLE INFRASTRUCTURE

TECHNICAL REPORT

ATIS is the leading technical planning and standards development organization committed to the rapid development of global, market-driven standards for the information, entertainment and communications industry. More than 200 companies actively formulate standards in ATIS' Committees, covering issues including: IPTV, Cloud Services, Energy Efficiency, IP-Based and Wireless Technologies, Quality of Service, Billing and Operational Support, Emergency Services, Architectural Platforms and Emerging Networks. In addition, numerous Incubators, Focus and Exploratory Groups address evolving industry priorities including Smart Grid, Machine-to-Machine, Connected Vehicle, IP Downloadable Security, Policy Management and Network Optimization.

ATIS is the North American Organizational Partner for the 3rd Generation Partnership Project (3GPP), a member and major U.S. contributor to the International Telecommunication Union (ITU) Radio and Telecommunications' Sectors, and a member of the Inter-American Telecommunication Commission (CITEL). ATIS is accredited by the American National Standards Institute (ANSI). For more information, please visit < http://www.atis.org >.

Notice of Disclaimer & Limitation of Liability

The information provided in this document is directed solely to professionals who have the appropriate degree of experience to understand and interpret its contents in accordance with generally accepted engineering or other professional standards and applicable regulations. No recommendation as to products or vendors is made or should be implied.

NO REPRESENTATION OR WARRANTY IS MADE THAT THE INFORMATION IS TECHNICALLY ACCURATE OR SUFFICIENT OR CONFORMS TO ANY STATUTE, GOVERNMENTAL RULE OR REGULATION, AND FURTHER, NO REPRESENTATION OR WARRANTY IS MADE OFMERCHANTABILITY OR FITNESS FOR ANY PARTICULAR PURPOSE OR AGAINST INFRINGEMENT OF INTELLECTUAL PROPERTY RIGHTS. ATIS SHALL NOT BE LIABLE, BEYOND THE AMOUNT OF ANY SUM RECEIVED IN PAYMENT BY ATIS FOR THIS DOCUMENT, AND IN NO EVENT SHALL ATIS BE LIABLE FOR LOST PROFITS OR OTHER INCIDENTAL OR CONSEQUENTIAL DAMAGES. ATIS EXPRESSLY ADVISES THAT ANY AND ALL USE OF OR RELIANCE UPON THE INFORMATION PROVIDED IN THIS DOCUMENT IS AT THE RISK OF THE USER.

NOTE - The user's attention is called to the possibility that compliance with this standard may require use of an invention covered by patent rights. By publication of this standard, no position is taken with respect to whether use of an invention covered by patent rights will be required, and if any such use is required no position is taken regarding the validity of this claim or any patent rights in connection therewith.

ATIS-0100031, *A Method to Display Metrics Related to the Robustness of the Undersea Cable Infrastructure*

Is an ATIS Standard developed by the **ATIS Network Performance, Reliability, and Quality of Service Committee (PRQC)**.

Published by

Alliance for Telecommunications Industry Solutions
1200 G Street, NW, Suite 500
Washington, DC 20005

Copyright © 2012 by Alliance for Telecommunications Industry Solutions
All rights reserved.

No part of this publication may be reproduced in any form, in an electronic retrieval system or otherwise, without the prior written permission of the publisher. For information contact ATIS at 202.628.6380. ATIS is online at < http://www.atis.org >.

Printed in the United States of America.

ATIS-0100031

Technical Report on

A Method to Display Metrics Related to the Robustness of the Undersea Cable Infrastructure

Alliance for Telecommunications Industry Solutions

Approved May 2012

Abstract

This Technical Report proposes a number of metrics to indicate the robustness of the Undersea Cable Infrastructure and a method for displaying the values.

Foreword

The Alliance for Telecommunication Industry Solutions (ATIS) serves the public through improved understanding between providers, customers, and manufacturers. The Network Performance, Reliability, and Quality of Service Committee (PRQC) develops and recommends standards, requirements, and technical reports related to the performance, reliability, and associated security aspects of communications networks, as well as the processing of voice, audio, data, image, and video signals, and their multimedia integration. PRQC also develops and recommends positions on, and foster consistency with, standards and related subjects under consideration in other North American and international standards bodies.

The mandatory requirements are designated by the word *shall* and recommendations by the word *should*. Where both a mandatory requirement and a recommendation are specified for the same criterion, the recommendation represents a goal currently identifiable as having distinct compatibility or performance advantages. The word *may* denote a optional capability that could augment the standard. The standard is fully functional without the incorporation of this optional capability.

Suggestions for improvement of this document are welcome. They should be sent to the Alliance for Telecommunications Industry Solutions, PRQC, 1200 G Street NW, Suite 500, Washington, DC 20005.

At the time of consensus on this document, PRQC, which was responsible for its development, had the following leadership:

P. Tarapore, PRQC Chair (AT&T)
J. Colombo, PRQC Vice-Chair (Verizon)
M. Linnell, Technical Editor (ACS)
S. Makris, Technical Editor (Ericsson)
C. Underkoffler, ATIS Chief Editor

Active Participants:

C. Dvorak	M. Niebert
E. Geelen	A. Nguyen
Y. Kogan	H. Pant
B. Linick	E. Rojek
M. Linnell	J. Schiavone
S. Makris	P. Tarapore
A. Morton	A. Webster

Table of Contents

Table of Figures

Technical Report on –

A Method to Display Metrics Related to the Robustness of the Undersea Cable Infrastructure

1 Scope & Outline

The Undersea Cable Infrastructure (UCI) has become a critical component of the global telecommunications infrastructure. No metrics currently exist to assess and track the robustness (resiliency, reliability, vulnerability, and growth) of the UCI. This Technical Report (TR) provides background information, a set of factors that influence the robustness, metrics associated with these factors, and a method of visualizing (based on an international standard) the metrics in a single diagram. The visualization methodology could be used by assorted interested parties.

This TR is organized as follows:

- Clause 1 – Scope & Outline.
- Clause 2 – Normative References.
- Clause 3 – Definitions, Acronyms, & Abbreviations.
- Clause 4 – Introduction to Undersea Cables: A description of the UCI and commonly used configurations, with comments on the advantages of each. Additionally, a description of general risks to the UCI is included.
- Clause 5 – Factors & Considerations: Discusses how select portions of the total UCI could be grouped and then describes factors that contribute to the resiliency, reliability, vulnerability, and growth of the portions of the network.
- Clause 6 – Selection of Parameters for Robustness: Describes possible metrics associated with the factors described in Clause 5.
- Clause 7 – One-view Visualization Methodology: describes and demonstrates a method for viewing the metrics described in Clause 6. Additionally, Clause 7 provides some insight into how the plots might be used by interested parties.
- Clause 8 – Further Considerations.

2 Normative References

The following documents contain provisions, which, through reference in this text, constitute provisions of this ATIS Standard. At the time of publication, the editions indicated were valid. All standards and technical reports are subject to revision, and parties to agreements based on this ATIS Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below.

2.1 ATIS References

- [ATIS-0100021] *Analysis of FCC-Reportable Service Outage Data*, 2008.[1]

[1] This document is available from the Alliance for Telecommunications Industry Solutions (ATIS), 1200 G Street N.W., Suite 500, Washington, DC 20005. < https://www.atis.org/docstore/default.aspx >.

2.2 ITU References

- [ITU-T 41] ITU-T Series G: Transmission Systems and Media, Digital Systems and Networks, G.Sup41, *Design guidelines for optical fibre submarine cable systems*, June 2007.[2]
- [P 505] ITU-T Recommendation P.505, *One-view visualization of speech quality measurement results*, November 2005.

2.3 Reference Literature

- [Sterbenz, et al] – James P.G. Sterbenz, David Hutchison, Egeman K. Cetinkaya, Abdul Jabbar, Justin P. Rohrer, Marcus Scholler, Paul Smith, *Resilience and Survivability in Communications Networks: Strategies, Principles, and Survey of Disciplines,* COMNET: Resilient and Survivable Networks Conference, March 9, 2010.
- [Omer, et al] – Mayada Omer, Roshanak Nilchiani and Ali Mostashari, *Measuring the Resilience of the Global Internet Infrastructure System*, IEE SysCon 2009, 3rd Annual IEEE International Systems Conference, Vancouver, Canada, March 23-26, 2009.

3 Definitions, Acronyms, & Abbreviations

3.1 Definitions

None identified in this document.

For a list of common communications terms and definitions, please visit the *ATIS Telecom Glossary*, which is located at < http://www.atis.org/glossary >.

3.2 Acronyms & Abbreviations

AIS	Automatic Identification System
ATIS	Alliance for Telecommunications Industry Solutions
ATM	Asynchronous Transfer Mode
BU	Branching Unit
CSR	Caribbean Sea Region
C&MA	Construction and Maintenance Agreement
DVD	Digital Video Disk
EDFA	Erbium Doped Fiber Amplifier
EIG	Europe India Gateway
Gbps	Gigabits per second
IEEE	Institute of Electrical and Electronics Engineers
IOR	Indian Ocean / Arabian Sea / Red Sea / Persian Gulf Region
ITU	International Telecommunication Union
ITU-T	International Telecommunication Union - Telecommunications
MPLS	Multi-Protocol Label Switching
MSR	Mediterranean/Black Sea Region
NAR	North Atlantic Region
NPE	Network Protection Equipment

[2] This document is available from the International Telecommunications Union. < http://www.itu.int/ITU-T/ >.

NPR	North Pacific Region
NSR	North/Baltic Sea Region
OVV	One-view Visualization
PDH	Plesiochronous Digital Hierarchy
PFE	Power Feed Equipment
PRQC	Performance, Reliability, & Quality Committee
ROV	Remotely Operated Vehicle
SAR	South Atlantic Region
SDH	Synchronous Digital Hierarchy
SEA-ME-WE-4	Southeast Asia–Middle East–Western Europe–4
SER	South East Asia Region
SPR	South Pacific Region
Tbps	Terabits per second
TR	Technical Report
TS	Terminal Station
TTE	Terminal Transmission Equipment
UCI	Undersea Cable Infrastructure
WDM	Wave Division Multiplexing

4 Introduction to Undersea Cables

The UCI is composed of numerous individual cable systems that carry voice, data, and video traffic between countries geographically separated by water. The infrastructure is driven by emerging traffic patterns and the technical capability of the diverse companies that plan, install, maintain, and repair undersea telecommunications cables.

While the UCI is extensive, serving every continent except Antarctica, the number of alternative undersea cables serving any one continent varies considerably. At present, many undersea cable systems operate across the Atlantic, Pacific, and Indian Oceans. The Atlantic is probably the most extensively served.

Currently, at least 32 undersea cable systems land in the contiguous United States (U.S.), Alaska, Hawaii, Guam, and Puerto Rico, with 18 Atlantic Coast cable landing sites and 22 Pacific Coast sites. Fifteen of the U.S. landing sites support major transoceanic systems.

Excluding communications with Canada and Mexico, more than 90 percent of the U.S. international voice, data, video, and Internet communications are carried on undersea cables. All modern cables, terrestrial-based as well as undersea, use fiber-optic technology to carry digital payloads (including voice-grade telephone, data, and traffic) and provide large-bandwidth capacity among countries (capacity measured in terabytes).

Satellite systems also carry international communications traffic. However, it is estimated that they carry less than 10 percent of international traffic. The relatively small proportion of international traffic carried by satellites is due to the increased bandwidth used by customers, satellite bandwidth constraints, latency issues, and higher costs compared with the costs of undersea cable systems. Nevertheless, satellites do have several advantages: they are able to reach more-isolated areas of the globe, they support mobile user requirements, and they can support broadcast-type services (e.g., weather, radio, video, etc.).

Most undersea cable systems have unique electronics and cable compositions; thus, they differ in make-up and capacity. Early systems, which were based on Plesiochronous Digital Hierarchy (PDH) technology, have been progressively phased out in favor of higher-capacity Synchronous Digital Hierarchy (SDH) and Wave Division Multiplexing (WDM) systems, which are more resilient and have better management characteristics. All modern undersea cables use fiber-optic technology. Common components include cable landing stations, wet and dry cable segments, repeaters, terrestrial backhaul, and network management capabilities.

4.1 System Architectures

The ITU [ITU-T 41] defines eight (8) different topologies for undersea cable systems. However, for practical purposes, the majority of networks are based on four (4) different topologies:

- Point-to-Point
- Trunk and Branch
- Ring and Branch
- Festoon.

Additionally, many carriers take advantage of multiple cable systems and create mesh architectures for their service network.

4.1.1 Point-to-Point Systems

This configuration consists of direct submarine link between two terminal transmission equipment (TTE) located in two different terminal stations (TSs). These systems may or may not contain repeaters. Advances in fiber and transmission equipment have made it possible to reach destinations up to 500 km (approximately 300 miles) away without intermediary amplification. Originally, repeaterless systems offered cost benefits because they did not require undersea regenerator units or power feed equipment. Now, optical amplifiers are commonly used at terminal points of repeaterless spans to boost transmitted signals or to pre-amplify received signals. These systems are typically 200–300 km long. Repeaterless systems are used among Caribbean islands, between the United Kingdom and its closest European neighbors (France, Belgium, and the Netherlands), and among British islands.

Figure 1 - Topology of a Point-to-Point System

4.1.2 Trunk & Branched Systems

This configuration connects several TSs including TTEs to a single trunk cable by means of branching units that allow the extraction of a part of the traffic in the direction of the TSs of the branches. Where cable spans exceed the distance limitations imposed by repeaterless technologies, repeaters are used. For these “long-haul” systems, “power feed equipment” (PFE) converts the power supply at the terminal station to high-voltage and regulated DC current, which is conducted along the cable’s internal metal structures before being extracted and used at repeaters (or amplifiers) along the cable. Repeaters (or amplifiers) contain electrical and optical components to either convert and regenerate or amplify the optical signal. Repeaters are spaced at specific distances from each other all along the cable to ensure a good signal from one end of the system to the other. Early long-haul cable systems carried a single optical channel per fiber and used repeaters, which converted the signal from optical to electrical form, cleaned up the signal, and re-transmitted it. In the current generation of systems, all the optical channels in a fiber are amplified together in an Erbium Doped Fiber Amplifier (EDFA). With repeaters, electrical power is required to light and regulate the pump lasers.

Branched systems are best adapted to long-haul routes that pass by a number of countries. Many of the newer long-haul systems are only lightly loaded, so a configuration that allows more than one country to use a single system’s capacity can increase the traffic load on the cable, thereby offering significant cost advantages. Also, if the cable can be branched in an undersea “branching unit” (BU), it is possible for one country to access the network without crossing the infrastructure or territory of another country. Examples of branched systems are cable systems between Europe and Southeast Asia, as well as, around Africa that branch en route into a number of countries.

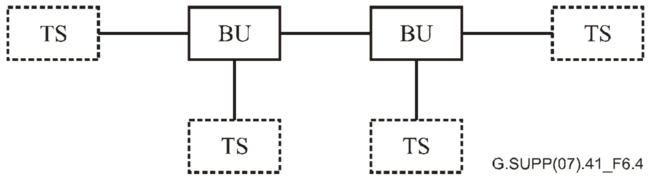

Figure 2 - Topology of Trunk and Brach System

4.1.3 Ring & Branched Systems

The ring configuration is essentially a set of connected, point-to-point cables having twice the requisite transmission capacity. In case any single failure occurs within the ring, such as a cable cut, traffic is routed around the ring – away from the inoperable segment – and on to its original destination. Shore-based transmission equipment provides automatic failure detection and switchover control for the entire ring without dropping a call.

The ring and branch extends the basic capability of the ring in a cost-effective manner with the addition of a branching unit. The branched-ring structure retains the self-healing nature of the ring. The branched ring, then, can be thought of as a merger between the trunk-and-branch and the ring, retaining most of the benefits of each. This configuration can be made in a number of ways, including hook-up through other networks. With proper planning, a network can be installed as a trunk-and-branch arrangement and upgraded later to a branched ring.

As optical cable and transmission systems evolved, technology advanced to the point where each new branched cable could carry more traffic than all its predecessor cables together. With this advance, it became possible to structure, over existing cables, a “protected” restoration path to be used in the event of cable damage or failures. The need for alternative, rapid path-switching necessitated the automation of processes and the introduction of “network protection equipment” (NPE) at cable landing stations. Ring system architectures are used across the Atlantic between the Americas and the United Kingdom.

For resiliency, it is important that ring systems not have locations that collapse the ring to a common point, thus removing the alternate path redundancy that was being relied upon to provide resiliency. (Collapsed ring systems or unprotected circuits may be used as long as a backup system is available in case of failure.)

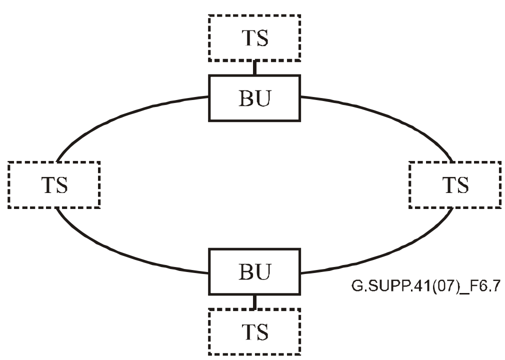

Figure 3 - Topology of Ring and Branched System

4.1.4 Festoon Systems

The festoon is basically a series of loops between major coastal landing points, and it is often deployed – though not always – as a repeaterless system. In anticipation of a future increased capacity requirement, these repeaterless applications are typically engineered with higher-fiber-count cables than those required for initial service. Thus, in the case of a need of additional capacity, terminal equipments are the only additional investments required. The architecture of a festoon frequently mirrors that of a typical, land-based installation. Such architecture may often be used as a supplemental, diverse route to an existing land-based system. This configuration is an increasingly popular alternative to a land-based system, especially when the continental terrain provides difficult installation and maintenance challenges.

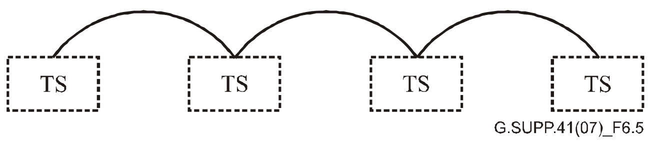

Figure 4 - Topology of a Festoon System

4.1.5 Mesh Networks

Mesh networks add resiliency to ring systems by using multiple diverse undersea cable paths. Meshing utilizes multiple undersea cable systems that are connected at land-based facilities. Electronic or optical switching enables instantaneous rerouting of traffic in the event of multiple undersea cable breaks. The 15,000 km (approximately 9,300 miles) Europe India Gateway (EIG) undersea cable project, completed in 2011, connects three continents (i.e., India, Africa, and Europe) and provides a second diverse landing in France. The EIG, together with the SEA-ME-WE-4 (Southeast Asia–Middle East–Western Europe–4) cable, for example, could utilize a mesh design and support telecommunications from Europe to the Middle East and extend to India/Southeast Asia. An example of a mesh network is shown in Figure 5, which depicts the mesh network that a major service provider has deployed in the trans-Atlantic region.

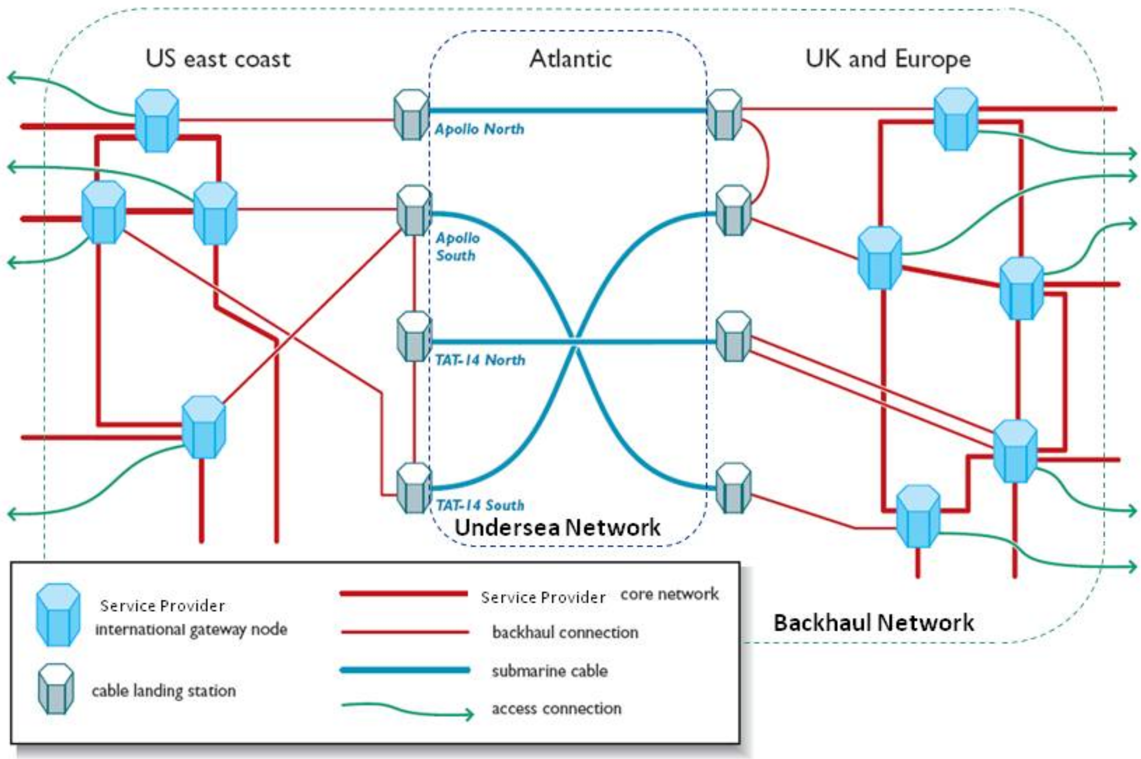

Figure 5 - Example of a Service Provider Mesh Network

4.2 Operators & Equipment Providers

An undersea cable typically terminates at the shore in a beach "manhole." There it connects with the dry segment, which typically passes through an underground conduit to its termination point at the cable landing station. Electrical or optical equipment in the station serves as the interface between the two segments.

Because of the considerable cost of building a trans-oceanic system (typically around $500 million for a transatlantic cable), undersea systems are rarely built by private owners. Instead, they are generally built by consortia -- groups of vendors, equipment providers and operators, and venture capitalists that come together to construct and maintain the system. In addition to establishing ownership relationships and developing a business model for selling or leasing the system's capacity, members of the consortia must consider vendor selection, system design and construction (including route and landing points), maintenance and provisions for upgrades, and, ultimately, retirement of the system. (A private system has the same considerations but is controlled by a single entity.) The company or companies that will act as the "maintenance authority" is defined in a consortium document known as a "construction and maintenance agreement" (C&MA). This formal agreement defines every aspect of a cable system, including costs, ownership, and maintenance responsibilities. The maintenance authority is responsible for the operations and maintenance of the system and is authorized to make decisions on behalf of all consortium members to ensure that the cable is properly operated.

Typically, maintenance agreements are a means of ensuring that ships are available to maintenance authorities for use in maintaining the cables. The ships are special-purpose vessels fitted with specialized equipment such as underwater “remotely operated vehicles” (ROVs), grapnels, sheaves, linear cable engines, splicing equipment, x-ray rooms, cable tanks, and dynamic positioning capabilities. In addition to providing for these specialized vessels, maintenance agreements also provide for the sharing of expenses for vessels across multiple systems, thereby reducing the cost. Agreements are geographically based with the intent of stationing ships, depots, and tools at central locations.

Because undersea cable systems are separate entities, a disruption of service in one system does not necessarily mean that other systems will be disrupted. In fact, traffic from an impaired system may be either dynamically or manually rerouted over unaffected systems. Currently, devices are being installed in several undersea cable systems at landing stations to enable optical switching from one cable to another, creating the same type of mesh architecture currently being employed in many terrestrial cable networks.

Various types of communication capabilities have been designed to utilize these architectures to provide wide-area networking, using Asynchronous Transfer Mode (ATM), Multi-Protocol Label Switching (MPLS), etc., protocols, which enable switching and network-restoration algorithms that enhance system availability, reduce latency, and provide a cost-efficient infrastructure.

Trends in undersea cables include a longer typical lifetime (approximately 25 years), a marked increase in the number of systems (currently, there are 223 undersea cables in service, with 18 cables put into service in 2009, 7 cables in 2010, 6 cables in 2011, and 5 cables thus far in 2012; additionally, there are 51 cables in the planning stages between now and 2014, with 34 of them scheduled for later in 2012), and an increased range for repeaterless systems. The trend toward fewer cables with higher capacities is continuing. The main equipment manufacturers now have systems with 16 fibers (8 pairs) in a loose-fill cable, with potential for total capacity of 10.24 Tbps [= 10 Gbps (Gigabit per second) x 128 WDM x 8 fiber pairs] capacity. At that capacity, one undersea cable can carry approximately 160 million telephone circuits simultaneously or transfer approximately 272 digital video disks (DVDs) among continents in one (1) second.

4.3 General Risks

The international undersea cable infrastructure traverses great distances and must operate in harsh (and in some cases restrictive) environments. Consequently, undersea cables are constructed to be reliable, with the least-accessible submerged portions designed to experience no more than three failures during a design life of approximately 25 years.

Although the infrastructure is technologically sophisticated and very reliable, certain limitations and extrinsic threats – both natural and man-made – can impact operations. These vulnerabilities must be understood and addressed by both service providers and customers that rely on highly resilient telecommunications to carry out critical operations. The following subclauses detail some notable risks to international telecommunications.

4.3.1 Natural Hazards

Undersea cable systems can be affected by seismic activities, erosion, storm damage, undersea landslides, and other geological events. Before the practice of burying cable began in the 1980s, the fault rate was 5 per 1,000 km (approximately 620 miles) of cable per year; with the burial of cable, together with increased awareness, the rate has decreased to less than 1 fault per 1,000 km per year.

An example of a fault due to a natural hazard was an underwater earthquake in December 2006 that caused a fiber cut to six (6) undersea cable systems in the Luzon Straits. Earthquakes, though of low incidence historically, can affect multiple cables and can occur at depths that make repair operations difficult and therefore lengthy. Newer undersea cables are equipped with ocean-bottom seismographs to provide real-time monitoring of seismic activities 24 hours a day. Natural hazards can displace cables from their original positions and can cause damage over a significant length of cable. Besides making for a challenging repair, such damage carries with it the risk that the quantity of cable required for the repair will exceed the spare stock held. Also, the number of ships needed to repair the multiple faults typical of damage from natural hazards may exceed the number available in the region. These circumstances, singly or in combination, may result in repair times far in excess of the norm.

4.3.2 Man-made Hazards

Fishing, dredging, and ship anchors have been known to damage undersea cable infrastructure. For example, a December 2008 fiber-optic cable cut near Egypt attributed to an abandoned ship anchor weighing 5 or 6 tons resulted in an 80 percent loss of connectivity to Egypt. Incidents of malicious damage have also occurred, but are not of significant frequency. Careful engineering of routes and installation of cable, coupled with offshore liaison with other seabed users, offers the greatest potential for further decreases in fault rates.

4.3.2.1 Cable-Landing-Station-Concentration Risk

Cable landing stations are points at which the undersea cable connects to the land-based infrastructure or network. Because of limitations on the locations of undersea cable landing points (they must be away from fishing lanes and trawler operations), landing stations are generally separated by no more than 300-500 km (approximately 200 or 300 miles) on any given coast.

4.3.2.2 Undersea Cable System Design

Placing undersea cable systems close together can pose a significant risk to international telecommunications. For example, an undersea earthquake near Taiwan (the Hengchun earthquake) caused an outage to six undersea cable systems in December 2006, resulting in a major degradation of telecommunications from Asia.

4.3.2.3 Component Failure & Time to Repair Undersea Cable Systems

Undersea cable systems are inherently more difficult to repair than terrestrial cable systems, because of the location of the cable and the complexity of the repair. Various external factors can affect the time needed for undersea cable repair, including repair-ship availability, repair-ship travel time to the fault location, repair permit availability, and poor weather conditions.

4.3.2.4 Landing Station Connectivity to Carrier Hotels

A *carrier hotel* is a co-location facility where multiple network, server, and storage gear are inter-connected. Some outages are the result of poor connections to these terrestrial networks from landing stations. The cause is generally physical fiber overlap or lack of carrier diversity. For example, because of regulatory restrictions in some countries, connectivity to the undersea cable landing station may be provided by only one carrier. Single-carrier services create an additional level of risk.

4.3.2.5 Physical Attack on Land Cable & Buildings

After leaving the sea, an undersea cable generally crosses a beach before entering a beach manhole. From there it is typically routed across many kilometers, using terrestrial construction techniques, until it reaches the cable landing station. Along this part of the route, the undersea cable is as susceptible to digging damage as a terrestrial cable. In addition, the cable path, together with areas around and within the landing station, is susceptible to physical attacks. Appropriately hardened physical security in and around cable landing stations will act as a strong deterrent to such attacks.

Geographic constraints and historical developments have resulted in both concentrations of service and limited-service areas, creating the potential for broad loss of service should damage occur in those areas. For example, environmental regulations may require that multiple cable systems pass through a coral reef at the same point, making all systems in the area subject to the impact of a single incident.

It is important to consider whether the physical separation between routes is sufficient to minimize the risk of multiple failures. Suppose, for example, that the cable crosses a sea-lane where vessels are under way with anchors deployed. The risk extends to water depths of 450 m, and separation between cables on the order of 20 km is necessary to minimize the risk. Similarly, vessels dragging while at anchor pose a threat to landings close to ports and associated anchorage areas. These risks can be mitigated through proactive use of Automatic Identification System (AIS) and/or port radar.

The crossing of a seismic plate also can result in multiple failures. It is normal that multiple cables cross a seismic plate, but the risk posed by multiple failures can be minimized by having the cables cross different fracture zones.

On-shore threats between the landing point and the cable landing station are predominantly from civil works. A process of control that requires approval before commencement of civil works can help mitigate the risk. These risks could result in a total loss of transoceanic telecommunications connectivity or degraded performance for mission-critical applications (higher latency or delay for data delivery).

Although undersea cables are a secure and high-capacity medium for transport compared with some other telecommunications media, there are vulnerable points in the systems where confidentiality of information can be compromised. Depending on the type and classification of the data being transported, end-to-end security using an encryption capability could be required. This is especially true if routing considerations across various systems are not known or are subject to change.

5 Factors & Considerations

5.1 Grouping of Systems for Indexing

There are two potential methods of grouping undersea cable systems for the purposes of resiliency analysis. The first method uses geographic regions that are consistent with the methods used by the undersea cable industry in the deployment of systems. However, there are a number of systems deployed that span multiple regions. How to handle the methodology for those systems needs to be considered. The second method examines major routes between geographic areas and groups cables that service the same route.

5.1.1 Regions

Regions are a key attribute associated with undersea cable systems. The Internet and private line services that are procured through these systems are designed by consortia and carriers on a per region basis. A *region* is defined as a geographic area that includes the grouping of undersea cable systems and supporting elements, designed to serve that specific geographic area. The UCI robustness analyses could include cables that go between landing stations, dedicated repair ships, depots, and maintenance organizations focused on a particular region.

The undersea cable systems are designed, deployed, and operated by consortia, carriers, and enterprises to serve a particular geological oceanic region or to connect multiple regions. The undersea cable system operators and carriers also have divided their cable assets by regions for ease of operations and maintenance.

Different regions have very different concerns and issues for UCI. For example, more than 40% of service disrupting undersea cable cuts between 2004 and 2009 occurred in the North Pacific Region (mainly at the Luzon Strait off the coast of Taiwan), due to earthquake and other natural causes. Meanwhile, earthquakes are not a major concern in the North Atlantic Region.

The Undersea Cable Industry has defined the following nine (9) major regions:

1. North Atlantic Region (NAR)
2. South Atlantic Region (SAR)
3. Caribbean Sea Region (CSR)
4. Indian Ocean / Arabian Sea / Red Sea / Persian Gulf Region (IOR)
5. Mediterranean/Black Sea Region (MSR)
6. North/Baltic Sea Region (NSR)
7. North Pacific Region (NPR)
8. South Pacific Region (SPR)

9. South East Asia Region (SER).

Figure 6 below depicts the nine regions; note in particular the major land masses that act as inter-regional interconnection points. It is in these land masses that we find hub cities and fiber-optic backhaul into that particular land mass.

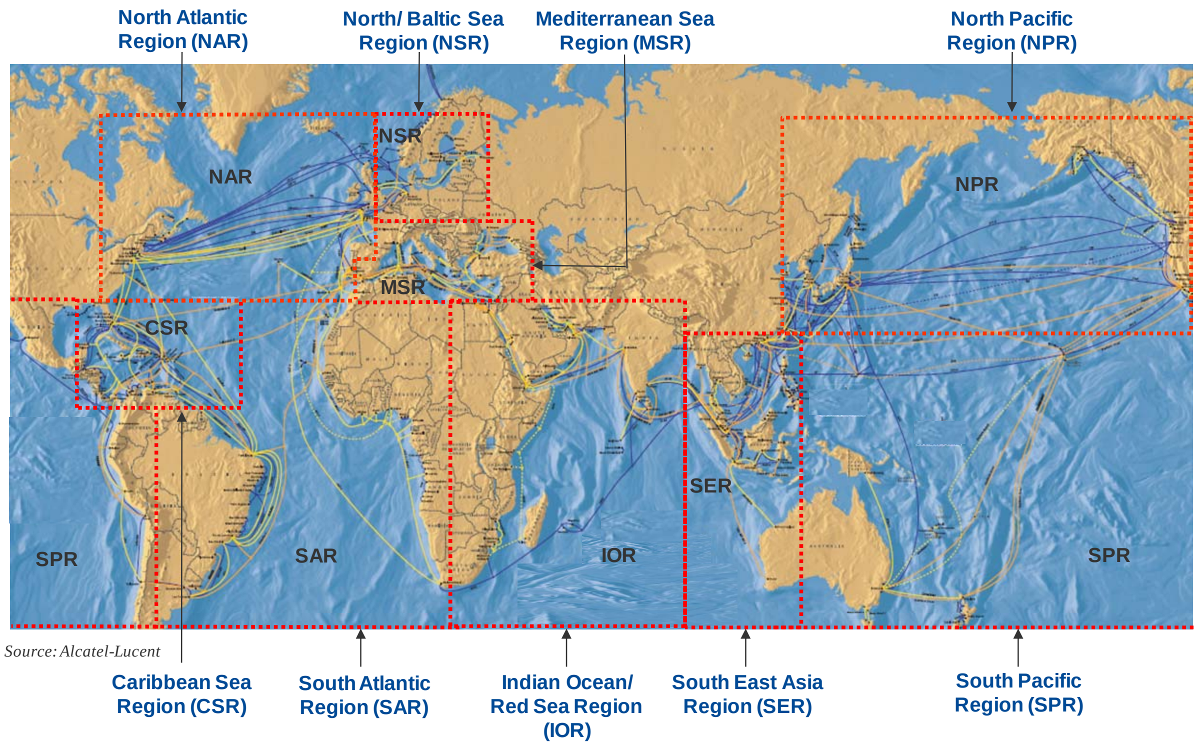

Figure 6 - Undersea Cable Regions

5.1.2 Routes

The second option for grouping cables would be to use major routes. The advantage of using the major routes is to group together cables that provide similar services and have the potential to be used for backup routing for other cables in the same grouping. Examples of some potential routes to use would be:

- North America – Europe
- North America – Asia
- North America – Caribbean / South America
- Europe – Middle East / Asia
- Europe – Africa.

5.2 Factors Affecting Resiliency, Reliability, Vulnerability, & Growth

This section contains a list of factors to consider including a brief description of the factors:

- *Number of Paths within the Defined Region or Route* –This factor would be proportional to the count of the number of distinct cable systems that transverse the route or region. Point-to-point, Festoon, and Trunk-and-Branch configured systems would contribute 1 to the count. Ring type systems would contribute 2 to the count.

- *Lit Bandwidth* – At any given point in time, a system is configured with a certain number of active fibers, with a certain number of wavelengths being used, and each wavelength has the potential to carry a certain bandwidth. The combined capacity of active components is considered the lit bandwidth.
- *Potential Bandwidth* – At the time a system is designed; the designers specify the total number of fibers that are in the cable. Additionally, the design capacity of each fiber is a factor of the number of potential wavelengths that could be carried and the bandwidth of a single wavelength. This number is typically fixed for the life of the system; however, with advances in technology, the number can change. The potential bandwidth is the capacity that could be made available if active components were configured for all fibers at all available bandwidths.
- *Connectivity between Systems* – Systems that are co-located at a landing station or have good backhaul connectivity (i.e., terrestrial fiber between the systems), have potential to act as backup routes for each other. Thus, some number representative of potential synergy would be a valuable factor.
- *History of Outages* – The historical count of outages for a system gives a good indication of the vulnerability of the system. The outage information could include number, duration, severity, cause, etc. Two values that are suggested as metrics are:
    - The number of outages experienced within the region or route within a specified period of time (the previous n months – a suggested value for n is 12); and
    - The maximum number of cables that were affected by a single event (e.g., earthquake, typhoon, etc.).
- *Availability of Repair Capabilities* – When an undersea cable has an outage, the repair time is typically measured in days; proximity of repair ships and spare equipment can help to minimize the outage time.
- *Regional Susceptibility to Natural Disasters* – Systems are more vulnerable when placed in a location with a history of natural disasters like earthquakes.
- *Regional Susceptibility to Man-made Outages* – Systems also are more vulnerable when placed in a location susceptible to external aggression, such as fishing, anchors, etc.
- *Age of Undersea Cable or Remaining Life of Undersea Cable* – This factor will take into consideration the aging of technology or the remaining time that the region's undersea cables will remain in service.
- *Upgradability* – This factor would take into consideration if the capability of a system could be upgraded (e.g., upgrading capability to 10G, 40G, and 100G).

6 Selection of Parameters for Robustness

It is the responsibility of the user of this Technical Report to select a set of parameters as an input for the One-view Visualization (OVV) methodology. Based on a study of the UCI, this clause provides a list of parameters that may be considered; this list is by no means exhaustive and does not exclude the use of additional or other parameters.

In defining a metric to quantify the robustness of the UCI servicing a region or route, the metric should be flexible enough that it could be used generically, examining all infrastructure in a region/route, or specifically, examining the infrastructure in a region/route used by a particular service provider. At an IEEE conference in Vancouver, Canada, [Omer, et al.] defined a metric for resiliency examining only the traffic load and traffic capacity of the system. While this metric may be useful for the modeling described in the paper, it does not take into consideration a number of factors associated with the infrastructure.

The proposed metrics are grouped into four categories – resiliency, reliability, vulnerability, and growth potential:

(i) *Resiliency* is the ability to adapt to an outage and restore Internet and private line services. This reflects the flexibility to adapt to changes and the richness of intra-connectivity that leads to rapid service restoration. Resiliency is the most important factor and contains four metrics (A_1 – A_4).

(ii) *Reliability* is the ability of the regional undersea cable infrastructure to consistently deliver end-to-end service(s) without degradation or failure. Consideration is given to outage history, susceptibility to disasters, and restoration capability. Reliability is the second most important factor and contains three metrics (A_5 – A_7).

(iii) *Vulnerability* is the extent to which a system will degrade when subjected to a specified set of environmental conditions (A_8 – A_{10}).

(iv) *Growth potential* is the ability to expand capacity in a timely manner to meet increased demand. This expansion capacity reflects the near-term growth potential. Expansion capacity is likely the least important of the metrics (A_{11} – A_{12}).

The proposed set of metrics will be the following quantitative values:

- A_1 (Number of Hubs) = A scaled value of the number of landing station areas (Hub) with three or more systems landing within the same city (more is better). This metric would reflect the availability of locations for rerouting during a failure.
- A_2 = A scaled value of the average number of cable landing stations per system (more is better). When a system lands at multiple locations, the availability of synergy increases.
- A_3 = A scaled value of the number of disjoint paths in the region/route (more is better). When multiple routes are available, the effects of a single failure are reduced (i.e., reduced chance of a single point of failure).
- A_4 = A scaled value of the average number of systems per Hub (see A_1). This factor indicates whether there is an appropriate quantity and diversity of UCI systems supported at the Hubs.
- A_5 = A scaled valued related to the number of outage events per region/route within the past 36 months (less the better). This metric reflects the risks associated with the region/route.
- A_6 = A scaled value related to the maximum number of systems affected by a single event within the past 36 months (less the better). This metric would reflect the severity of risks within the region/route.
- A_7 = A scaled valued related to the ratio of cable repair ships available in a region or for a route (more the better) to the number of paths in that region/route (see A_3). Availability of repair capabilities reduces the expected downtime if an event occurs.
- A_8 = A scaled valued related to Regional susceptibility to natural disasters. It is based on historical information) based on regional geo-seismic maps and seismic history.
- A_9 = A scaled valued related to Regional susceptibility to man-made disasters (an index of 1 to N, based on historical information from outages attributable to external aggression, such as fishing, anchors, etc.).
- A_{10} = A scaled valued related to the age of the undersea cable or the remaining life of the undersea cable. It is based on the aging of technology or on the remaining time that the region's undersea cables will remain in service).
- A_{11} = A scaled valued related to the ratio of un-lit capacity to total capacity (higher is better, has more growth potential).
- A_{12} = A scaled valued related to the capability of a system to be upgraded (e.g., upgrading capability to 10G, 40G, and 100G).

For displaying the metrics, each would be normalized to a zero to one scale with the larger the value, the better the results of the metric.

7 One-view Visualization Methodology

The "One-view Visualization methodology" was standardized in ITU-T Recommendation P.505 [P-505] for use in displaying a set of transmission measurements associated with a communication experience. A similar methodology can be used to display a set of robustness metrics associated with an undersea cable route or region. The method can be summarized as follows:

- Quick and easy recognition of parameters with undesirable values.
- Assessment of strengths and weaknesses of routes or regions relative to others.
- Easy comparison of different routes or regions based on the corresponding representations.
- Easy extension of the representation by new parameters relevant to robustness in the future.

A representation based on circle segments ("pie diagram", "star plot") is recommended (see Figure 7).

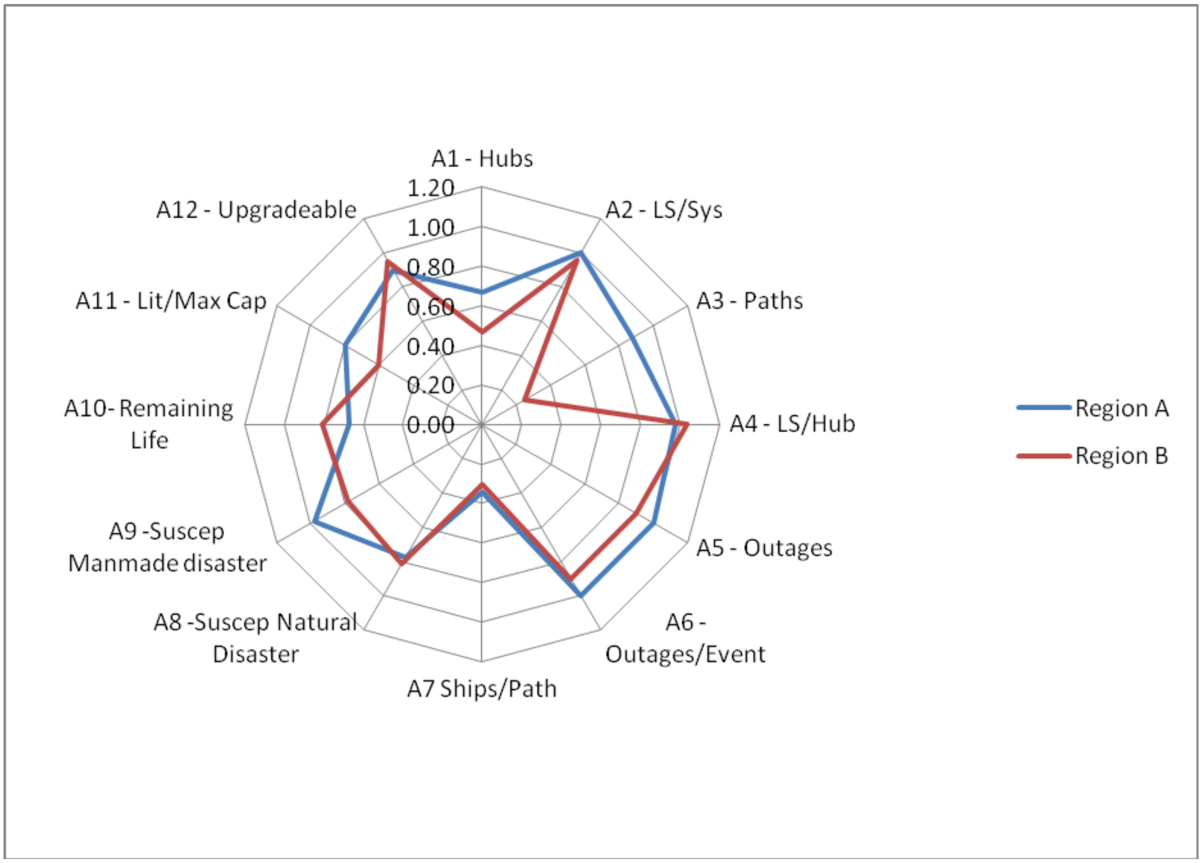

Figure 7- Example Star Plot for One-view Visualization

The number of the represented parameters determines the size of the individual circle segments. Similar to a "cobweb" representation, the axes are shown with a common origin. The individual segments have the same size (spanned angle 360°/number of selected quality parameters). It is recommended that the number of different parameters visualized in one diagram should not exceed twelve (12). Moreover, the representation of individual segment sizes is not interdependent, thus guaranteeing the independence of the different robustness parameters from each other. Therefore, this pie diagram offers the following advantages:

- It presents an independent representation of individual robustness parameters.
- Segment sizes are determined by the number of selected parameters and are identical. In a possible extension step, the segment size could be adjusted according to the contribution of individual robustness parameters to total robustness. However, unless such a measure or weighting rule is available, an identical segment size is recommended.

- Segment size (radius) is a measure for the robustness of the route regarding this parameter.
- By means of a suitable axis scaling, a concentric circle around the origin can be defined which represents a minimum robustness measure. Falling below this segment size (radius) indicates an undesirable condition.
- By means of a suitable color selection, results lying within the tolerance or transgressing the limit values can be easily visualized.

Figure 7 gives a representation example for a selection of the twelve (12) parameters described in the previous section. Note that this representation does not correspond to a real UCI region/route, but only serves as an example. All parameters were transformed to ensure that a value near zero is worse than a value near one.

8 FUTURE CONSIDERATIONS

As in the case with Outage Index for the FCC-reportable outages [ATIS-0100021], ATIS has introduced a taxonomy for industry discussions. It is critical that this ATIS Standard be leveraged and shared with other standards bodies, and the UCI industry at large, to promote the international adoption of a taxonomy to measure and discuss UCI robustness. This methodology could be used by various stakeholders for planning purposes.

There are at least four (4) stakeholder groups:

1. Submarine cable owners/operators;
2. Carriers that lease service from the owner / operators;
3. Enterprise or government entities that lease services from the carriers; and
4. Other standards bodies.

The adoption of a taxonomy would be of particular interest to other stakeholders ,such as the financial industry, which rely upon global infrastructure to conduct their business. Each of these groups could have differing interests as to which parameters are the most important and what criteria should be used for comparison. For example, one group may want to observe trends over time, while another may want to compare alternate routes to get to the same destination. This methodology allows for a diverse set of comparisons.