Satellite Communication Systems Onboard Spanish Oceanographic Vessels

Performance and optimization analysis

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***Abstract* — This article describes the architecture of two broadband satellite communication systems using a Very Small Aperture Terminal which have been installed on two Spanish oceanographic research vessels. The potential use, equipment and their characteristics are studied and compared. Analysing four parameters (jitter, round time trip, package loss and throughput), system configuration has been modified from the launch until the final optimization in order to improve TCP/IP based communications. The hardware selection is fundamental to the successful implantation of the systems, which has to guarantee the quality of satellite services. Satellite channels can affect TCP/IP protocols, but these difficulties were overcome with correct system configuration. Despite the service being operated correctly, several tests had to be done periodically to improve it and check the satellite service conditions. After the optimization of equipment configuration and network parameters on VSAT links of both vessels, effective and stable links have been obtained for web navigation and VPN communication.**

Keywords-Satellite Communications; Oceanographic Vessels; Virtual Private Networks; Very Small Aperture Terminals, TCP/IP

I. INTRODUCTION

The Marine Technology Unit (*Unidad de Tecnología Marina* - UTM) of the Spanish Research Council (*Consejo Superior de Investigaciones Científicas* - CSIC) carries out activities for the logistic and technological support of oceanographic vessels and polar stations, as well as for technological development in marine science.

Two Broadband Satellite Communication Systems were installed in two of our vessels in 2008. In *BO Sarmiento de Gamboa* a VSAT Communication System in C band was installed with a data transfer rate of 192 kbps (CIR, Commited Information Rate) and a burst capacity of 256 kbps (MIR, Maximum Information Rate) which can be increased to 5 Mbps. While in *BIO Hesperides*, following Navy specifications (the ship-owner) a TNX75 Communication System in X band was installed with a data transfer rate of 128 kbps (CIR) which can be also increased to 5 Mbps.

Apart from the advantages that an Internet access has had for the researchers, one of the most important characteristics of this Broadband System is the possibility of configuring a Virtual Private Network (VPN) between the vessels and the UTM main offices on shore (Land-Site). This VPN permits remote administration of servers, database synchronization, etc.

Therefore, a VPN has been installed between the vessels and where the UTM has its Land Site installations. This network enables real-time data transmission and remote systems control and operation. Furthermore, web browsing is possible and an IP telephone system has been installed.

A minimum data transfer of 120 MB is generated every day between the ship and UTM land site, including email exchange between servers, database synchronization and data broadcast in real-time for ship navigation and survey general purpose data (Table I).

TABLE I. EXAMPLE OF DAILY TRAFFIC THROUGH THE VPN (SHIPS TO/FROM LAND SITE)

	Mail	***BBDD Synchr***	***Data Broadcast***
Daily traffic VPN	105 MB	7.0 MB	16 MB

The installation of this kind of networks is not easy and several difficulties can appear. Therefore, an optimal configuration of protocol architecture has to be looked for. In satellite communication where TCP/IP protocols are used, data links are very sensitive to latency, asymmetric links, and package loss due to congestion or transmission errors. [1].

Satellite channels may degrade the performance of TCP due to long feedback loop damaging interactive applications such as *telnet*, as well as some of the TCP congestion control algorithms, and large DBP (delay bandwidth product, that defines the amount of data that has been transmitted but not yet acknowledged to fully utilize the available channel capacity.

Compared to wired links, the main problem is latency in the satellite communication. The propagation time for a radio signal to travel twice to geo satellite is 239.6 milliseconds. Therefore, the propagation delay for a message and the corresponding reply, round trip time (RTT), could be at least

558 ms. The RTT is not based solely on the satellite propagation time and can be increased by other factors in the network, such as the transmission time and propagation time of other links in the network path and queuing delay in gateways. [2]

A long RTT must also be taken into consideration to adjust TCP parameters. The standard maximum TCP window size (65.535 bytes) is not enough to allow a single TCP connection to utilize the entire bandwidth available on some satellite channels. In order to optimize TCP throughput that is limited by the following formula: *throughput = window size / RTT*, maximum TCP window size must be adjusted.

It is recommended that those utilizing satellite channels in their networks should use *Path MTU Discovery* or adjust *MTU* values manually to determine the maximum packet size a connection can use on a given network path without being subjected to IP fragmentation. It is also recommended to use a forward error correction (FEC) to improve the bit-error rate (BER) [2].

In current commercial Very Small Aperture Terminal (**VSAT**) systems, the losses for transmission errors are reduced to the minimum due to codification algorithms and modulation equipment. A symmetric link is guaranteed by contractual terms and the congestion problems from terrestrial network are overcome with a backbone link with separate management and service quality.

Both vessels are managed by UTM owned by different ministries. Administrative requirements were different at the time of choosing the satellite service providers. During start-up their services and their architectures were very different and they were modified until the problems were overcome, so both systems can currently offer the same services.

In this article, first the two systems and their environment are described in order to understand the structure and the differences between both ships. Thenthe configuration process is related from start-up until final optimization. In next chapter, the methodology and the results of analysis are explained. Finally results and conclusions are expounded.

II. System Description

A. General schema

The broadband satellite service of UTM ships has a capacity which enables IP networking in permanent connection. For that, VSAT technology is used which connects the ships to the satellite network. The satellite service providers are Seamobile and Hisdesat. Both of them use geostationary satellites (orbiting at 35,786 km) and a large set of ground stations to provide coverage around the globe except the polar areas (their effective coverage is between 70 º N and 70 º S).

The terminals used onboard work with the C and X band. The dimension of the antennas (2.4 m diameter) enables data transmission rates close to 5 Mbps in a global coverage scenario. With the current contract the providers guarantee a link with a minimum symmetrical bandwidth of 128Kbps.

Since the key element of both systems is the VPN connection between the vessels and the UTM Land Site, the system architecture is virtually identical in both cases, although the receivers work in different bands. The diagram for that architecture is detailed in Figure 1, referring to the three locations involved: vessel, land backbone or teleport site, and UTM Land Site:

1) Vessel Site: On board ships there is a gyro-stabilized antenna and position control unit, one modem, and the network equipment that enables IP routing, VPN establishment, access control lists, management of service quality, and links to the vessel network. In both systems the IP equipment is the same brand and model (Cisco 2800 Series routers), while the electronic equipment for satellite link is specific to each case. The configuration of these routers allows VPN establishment and Access Control Lists (ACLs) which allow specific computers to access Internet or Land Site Local Area Network.

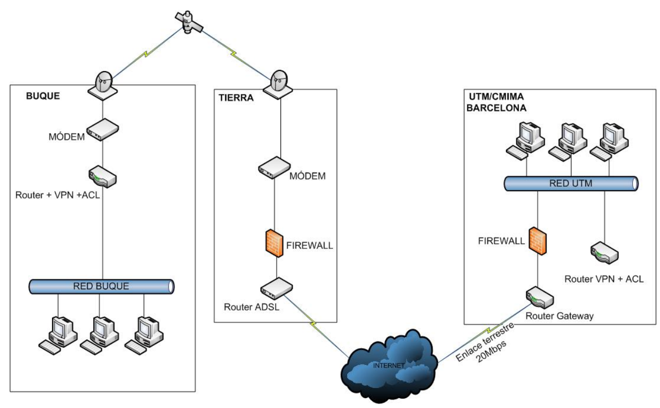

Figure 1. General schema of architecture of broadband system communication on board "BO Sarmiento de Gamboa" and "BIO Hesperides"

2) Teleport Site: In order to allow the link between the satellites and the data backbone network or public switched telephone network (PSTN), the provider needs specific equipment. In this site the following elements are available (apart from those from the management service provider): a modem for the satellite link, IP router for Internet connection and firewall. This last security element has been placed in this site in order to prevent the waste of bandwidth due to spam traffic.

3) UTM Land Site: This equipment corresponds to the end of VPN and is located in the UTM Land Site (Barcelona). The VPN links are managed by a router. This is the central node in the Private Network which is extended between the UTM site and the oceanographic vessels. Some computers have permission to access the ships' networks from the UTM LAN, these are specific in the ACL configuration.

B. *"BO Sarmiento de Gamboa" system: C Band*

The "BO Sarmiento de Gamboa" system has a *Seatel 9797A-67* antenna (2.5 m diameter), a control unit *Seatel 113105* and modem *iDirect 5150* with embedded TCP acceleration and optimization. This configuration allows us a data transfer rate of 1Mbps without modifications for upstream and downstream links. This rate could be increased to 3.5 Mbps just by changing the antenna Block Down Converter.

The satellite link is conducted through the following satellites: *Intelsat-903/906* and *NSS-5*, using the *Seamobile* teleport network in the USA and Europe.

With the current contract, *Seamobile* provides the UTM with a data channel of 192 kbps (CIR) for IP data and a voice channel which allows four simultaneous calls. These are managed by a VoIP specific router without interaction with the data channel (Figure 2).

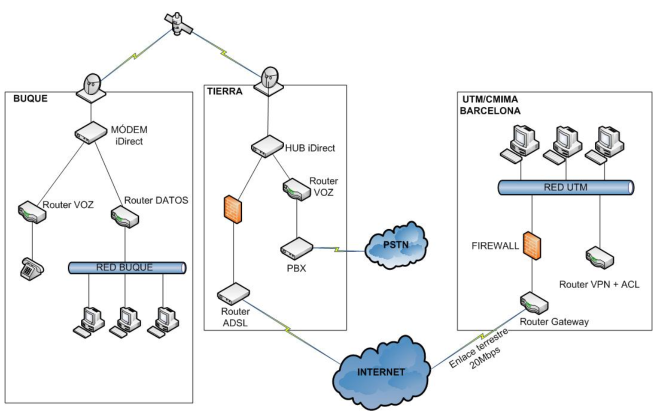

Figure 2. Diagram of "BO Sarmiento de Gamboa" broadband system

C. *"BO Hesperides" system: X Band*

On board the "BIO Hesperides" a satellite terminal is mounted with two simultaneous carriers in X band which correspond to two different transponders of the satellite whose maximum frequency separation is 500 MHz. One of these carriers is used for encrypted military communications and the other for scientific communications. The antenna model is *Seatel 9797* whose electronics have been adapted to the characteristics of the X band (TNX75 model).

For our communication, two *Paradise PD-25* modems were installed one of them in the vessel and the other in the teleport station. They are located in Maspalomas (Gran Canaria). This modem enables IP traffic with excellent BER versus Eb/No using Turbo-Codec FEC. This device offers the possibility of using the right FEC for low power spectral density and Automatic Power Control, but it does not have embedded TCP acceleration.

The distinctive element of the "BIO Hesperides" is the installation of *Expand* accelerators on the vessel and at Land Site. These accelerators are configured in LAN mode in order to process only the traffic of some designated computers.

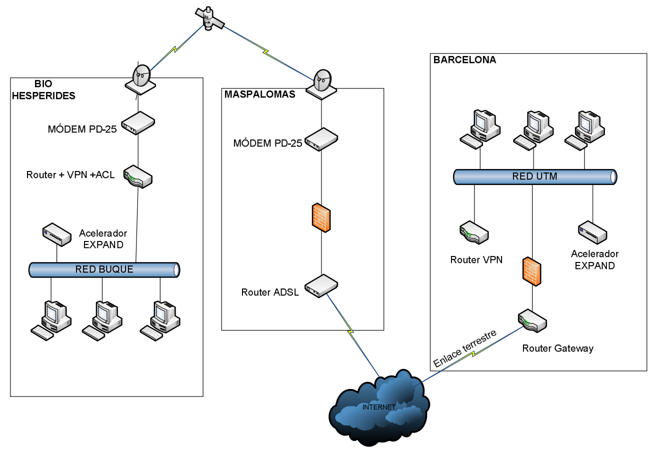

Figure 3. Diagram of "BO Hesperides" broadband system

Land link to Internet is done via an Asymmetric Digital Subscriber Line (ADSL) router with two dedicated lines of 256 kbps, whereas the configuration of the elements for VPN and ACL is the same as for the "BO Sarmiento de Gamboa" system.

Currently the satellite link is conducted through *Spainsat* and *Xtar-eur* satellites, using *Hisdesat* teleport at Gran Canaria. According to contractual terms, the communication service provides a data channel of 128 kbps (CIR) for IP data that can be increased to 5 Mbps using accelerators (Figure 3).

III. SERVICE CHARACTERISTICS FROM START-UP TO OPTIMIZATION

Both systems were installed on the vessels almost simultaneously, but initially their performances were very different in each case, until the equipment configuration and optimization of the system were carried out.

Next, the initial configuration and the process tothe final state are detailed, and in the next chapter communication improvements are studied according to four main parameters (jitter, bandwidth, RTT and packet loss).

The "BO Sarmiento de Gamboa" start-up system didn't have any differences to the initial design made by the satellite service provider. Network traffic measurements showed a symmetric bandwidth link according to the contract. The packet loss rate was close to 1.5% including traffic inside VPN (Figure 4-5). Currently there is no change in the configuration of the standard values on-board computing facilities, except the MTU which was modified to optimize the link between the ship and Land Site.

The "BIO Hesperides" system presented a very different scenario on its installation. Although connection with HTTP servers was possible, the VPN link was extremely poor, despite using same IPSec protocol and encryption parameters used on the "BO Sarmiento de Gamboa" system. In this initial situation, the accelerators were configured only to improve Internet traffic and not VPN traffic (An Expand accelerator was located on the teleport site in Maspalomas). The analysis of the performance in this situation showed high packet loss rate (reaching 80%), and continuous changes on throughput values (Figures 4-5).

The PING tool is used to verify if packet fragmentation exists, and to look for the optimum MTU value. In the “BO Sarmiento” system, iDirect modems are capable of reassembling fragmented packets, but PD-25 modems in the “BIO Hesperides” cannot do that, causing high packet loss rate. Several tests with different MTU values were done to find the optimal MTU value that was set finally around 1400. After this change the quality link was improved considerably (Figure 4-5).

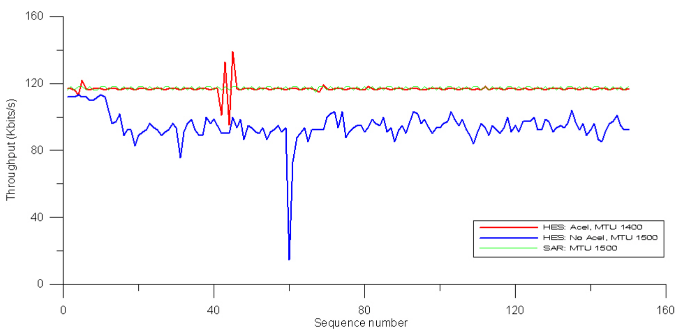

Figure 4. Effective bandwidth at initial conditions at “BO Sarmiento” (green line) and “BIO Hesperides” (blue line). Also values for “BIO Hesperides” (red line) after MTU and Accelerator optimization

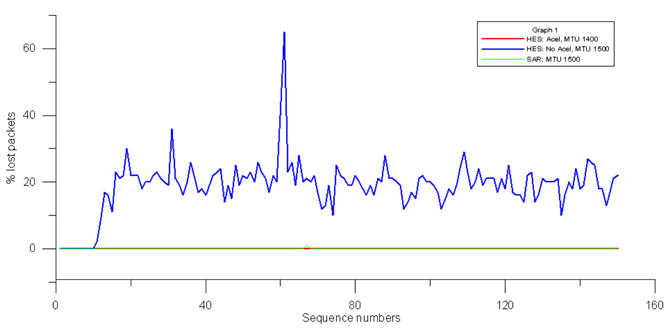

Figure 5. Packet loss percentage at initial conditions at “BO Sarmiento” (green line) and “BIO Hesperides” (blue line). Also values for “BIO Hesperides” (red line) after MTU and Accelerator optimization

After this, the geographic location and configuration of the accelerators were changed to work within the VPN link. The accelerator on the teleport site was moved and integrated on the UTM Land Site.

Although some related works [2] suggest that TCP window size should be adjusted to RTT values and the desired maximum throughput. This improvement was discarded to avoid the performance reduction in the on-board LAN as a collateral effect.

IV. Analysis of Equipment Configuration and Protocols

In order to evaluate the communication performances in the network, we have different tools. We have chosen two main tools, IPERF and PING.

IPERF [3] is a bandwidth measurement tool which is used to measure the end-to-end achievable bandwidth, allowing variations in parameters like TCP window size and the number of parallel streams. IPERF approximates the cumulative bandwidth (the total data transferred between the end-hosts over the total transfer period) to the end-to-end achievable bandwidth. In this case we use the bandwidth between the vessel and the CMIMA to send packets in both directions, evaluating packet loss and jitter variations under different conditions.

The measurements presented were made with this tool sending packets in both directions into the VPN link, using a bandwidth of 117kbps along 1800 seconds probe.

Jitter [4] is the variation in the latency of packets at the destination. If the jitter value is high, the performance in some time-sensitive applications, such as voice over IP, might be affected. This can be caused by network congestion, synchronization loss or different routes taken by the packages to arrive at destination. In a terrestrial connection the jitter should be lower than 100 ms to be compensated adequately. However, the jitter in communications between vessels is significantly higher.

PING (Packet Internet Groper) [5] utilizes the ICMP protocol’s mandatory ECHO request datagram to elicit an ICMP ECHOREPLAY from a host or gateway. This tool lets us know the round-trip delay time or round-trip time (RTT) corresponding to the period of time in milliseconds that is needed to go and come back between source and destination hosts. Usually, this delay should be not higher than 200 ms in terrestrial communications, and around 700 ms in satellite communications.

Furthermore, the RTT value has been analysed with another network management tool, HPING3 [6] a command-line oriented TCP/IP packet assembler/analyser. The interface is inspired to the ping (8) Unix command that is able to send ICMP echo requests, but also supports TCP, UDP, ICMP and RAW-IP protocols. HPING3 works sending a TCP SYN packet to a remote TCP port, and then the RTT employed by the corresponding ACK signal to come back is shown.

In the “BIO Hesperides”, several tests were done with IPERF tools. Initially the delay between the two hosts, connected directly to the vessel modem and the teleport modem, was evaluated for 7200 seconds. This measure should avoid any interaction or effects introduced by other network equipment (routers and accelerators).

The next measurement set was made through the routers after configuring the VPN and the accelerators in "BYPASS" mode. Finally, the accelerators were activated in "LAN" mode and the different results were compared. Then a new measurement set was made using PING for 1200 seconds.

In the “BO Sarmiento de Gamboa”, IPERF and PING tool measurements were made, for 1800 and 1200 seconds respectively, with different MTU value, since accelerators had not been installed there.

All the tests were done with the vessels working in two surveys in different locations. “BIO Hesperides” was in Brandsfield Sea (Antarctica), and “BO Sarmiento de Gamboa” was in front of the NW Spanish coast.

A deeper analysis of data has to be made, repeating experiments more often, and taking into account the geographical position of ships, and the real use of link during the survey produced by the scientific work.

A description follows commenting on the main results of the parameters that have been obtained by changing the conditions of links, taking into account that:

- In all the figures, situation “1” corresponds to tests made through accelerators in LAN mode and the MTU value to 1400 for every host (Optimal situation).
- Situation “2”corresponds to communication tests through accelerators in LAN mode and the default MTU value (1500) for every host.
- Situation “3” corresponds to communication tests through accelerators in BYPASS mode and the MTU value to 1400 for every host.
- Finally, situation “4” corresponds to communication tests through accelerators in BYPASS mode and the default MTU value (1500) for every host (Worst situation).

A. *Jitter analysis*

The jitter results were collected by injecting bidirectional traffic between the vessels and Land Site for 1800 seconds, with the four different conditions.

Initially the jitter analyses was made with the arithmetic mean values, but after plotting the data distribution of the 1800 seconds probe, it was observed that most of the values were low and only a few of them were very high converting the “arithmetic mean” to a non representative value (Figure 6). Instead “median” was used as a measure of central tendency excluding the extreme values.

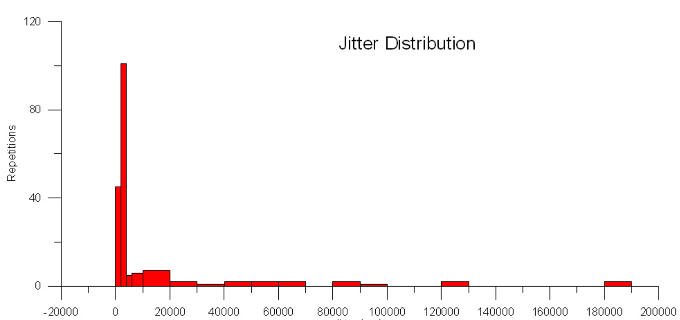

Figure 6. Distribution of jitter variable. Note that most of values are between 2000-4000ms.

The Jitter evolution can be seen below (Table II and Figure 7) for “BIO Hesperides” (red and blue marks). An important improvement in these values is shown when the accelerators are introduced, going from 11000ms values without accelerators to 2000-3000ms with them. The jitter is also slightly lower for the downloading link than the uploading sense. According to this information, there is no symmetry in the satellite link. In both vessels, jitter values are higher when the MTU is not optimized. For the“BO Sarmiento de Gamboa” the lowest jitter is around 6000 ms which is greater than the best acheived for the “BIO Hesperides”.

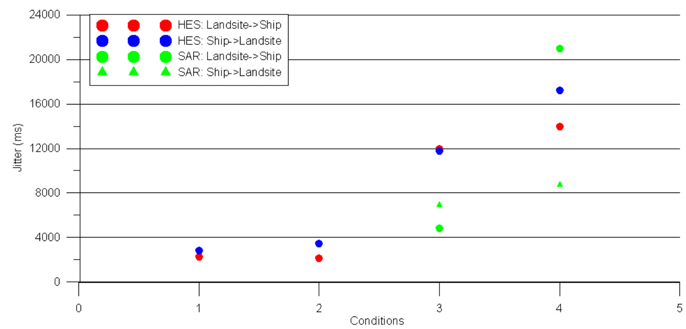

Figure 7. Graphical Jitter (ms) distribution along the 4 different scenarios in both link directions: 1- Optimized MTU and Accelerator placed; 2- Standard MTU and Accelerator placed; 3- Optimized MTU without Accelerator; 4- Standard MTU without Accelerator.

TABLE II. MEDIAN JITTER (MS) VALUES ALONG THE 4 DIFFERENT SCENARIOS AND OVER MODEM TO OVER MODEM LINK

		Land->Ship	***Ship->Land***
BIO Hesperides	Modem to Modem	6997	4603
	1: Acc & MTU1400	2278	2846
	2: Acc & MTU1500	2115	3436
	3: No Acc & MTU1400	11948	11793
	4: No Acc & MTU1500	13963	17245
BO Sarmiento de Gamboa	1: MTU 1400	4848	6912
	2: MTU 1500	20999	8734

B. *Throughput analysis: Total data transmitted*

For the “BO Sarmiento de Gamboa” the data transfer rate is optimal and the data losses are virtually null even with the default MTU value.

For the“BIO Hesperides”, when accelerators are not on line, data transfer decreases. MTU optimization is more important in magnitude in the reduction of data loss (Figure 8 and Table III).

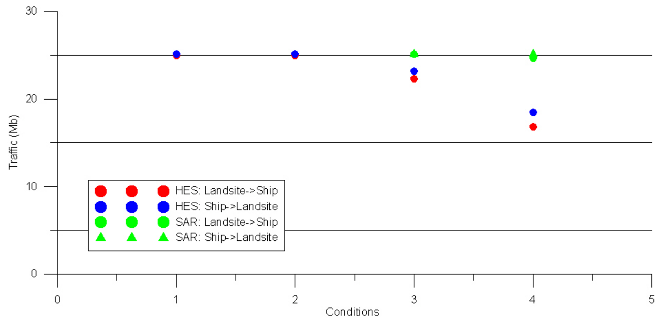

Figure 8. Graphical packet loss percentage along the 4 different scenarios in both link directions: 1- Optimized MTU and Accelerator placed; 2- Standard MTU and Accelerator placed; 3- Optimized MTU without Accelerator; 4- Standard MTU without Accelerator.

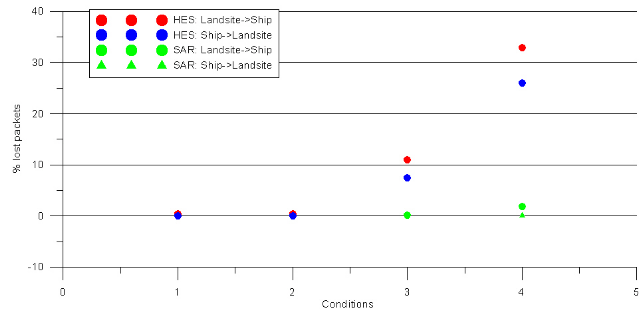

Figure 9. Graphical packet loss percentage along the 4 different scenarios in both link directions: 1- Optimized MTU and Accelerator placed; 2- Standard MTU and Accelerator placed; 3- Optimized MTU without Accelerator; 4- Standard MTU without Accelerator.

TABLE III. TRAFFIC (MB) VALUES ALONG THE 4 DIFFERENT SCENARIOS AND OVER MODEM TO OVER MODEM LINK

		Land->Ship	***Ship->Land***
BIO Hesperides	Modem to Modem	108.7	108.5
	1: Acc & MTU1400	25	25.1
	2: Acc & MTU1500	25	25.1
	3: No Acc & MTU1400	22.5	23.2
	4: No Acc & MTU1500	16.8	18.5
BO Sarmiento de Gamboa	1: MTU 1400	25.1	25.1
	2: MTU 1500	24.7	25.1

C. *Data packet loss analysis*

On the"BIO Hesperides", the percentage of lost packets between modems is higher than 1% on both link directions. After the installation of the rest of the equipment, the lost packets percentage is very high (18-19%) with a default MTU value. After optimizing the MTU, the percentage descends to 5-10% which is still not an acceptable rate for stable communication. Finally, the action of accelerators drastically reduces the data loss to 0.5%.

On the "BO Sarmiento de Gamboa", the loss of packets is around 2% without the MTU optimization and goes to 0% when the MTU is 1400 (Figure 8 and Table IV).

TABLE IV. PACKET LOSS PERCENTAGE ALONG THE 4 DIFFERENT SCENARIOS AND OVER MODEM TO OVER MODEM LINK

		Land->Ship	***Ship->Land***
BIO Hesperides	Modem to Modem	1.8	1.1
	1: Acc & MTU1400	0.36	0
	2: Acc & MTU1500	0.44	0.06
	3: No Acc & MTU1400	11	7.5
	4: No Acc & MTU1500	33	26
BO Sarmiento de Gamboa	1: MTU 1400	0.18	0.01
	2: MTU 1500	1.8	0.01

D. *RTT analysis*

The distribution of RTT values shows a high quantity of values near a central value (600-800ms), and some higher values that makes the arithmetic mean a non representative RTT value. We will also refer, for this case, to the median value as the most representative measurement for RTT.

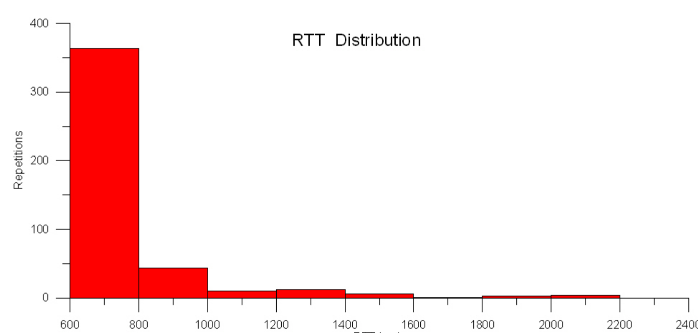

Figure 10. Distribution of RTT variable. Note that most of values are between 600-800 ms.

Some tests have been made through the VPN and going out of the tunnel (from ship to Internet). From the "BIO Hesperides" the RTT is slightly lower going through the

VPN and also is slightly lower than the "BO Sarmiento de Gamboa" values too. Both ships show very stable values around 700-800 ms.

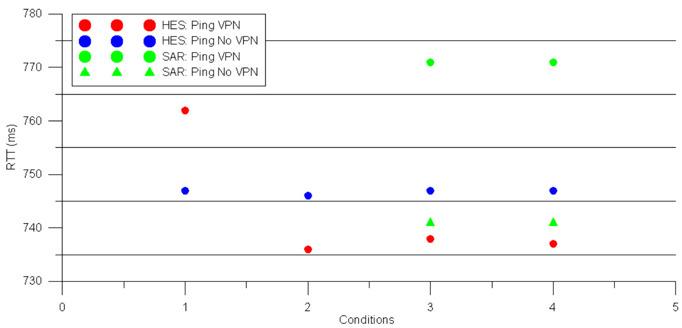

Figure 11. Graphical RTT values along the 4 different scenarios in both link directions: 1- Optimized MTU and Accelerator placed; 2- Standard MTU and Accelerator placed; 3- Optimized MTU without Accelerator; 4- Standard MTU without Accelerator

TABLE V. RTT VALUES ALONG THE 4 DIFFERENT SCENARIOS AND OVER MODEM TO MODEM LINK, BETWEEN SHIP AND LAND SITE (USING VPN) AND BETWEEN SHIP AND INTERNET (NO VPN USED).

		VPN	*No VPN*
BIO Hesperides	1: Acc & MTU1400	762	747
	2: Acc & MTU1500	736	746
	3: No Acc & MTU1400	738	747
	4: No Acc & MTU1500	737	747
BO Sarmiento de Gamboa	1: MTU 1400	771	741
	2: MTU 1500	771	741

Using the HPING3 tool, "SYN" packets are sent from Land Site to port 80 at web-servers on-board. RTT values are around 730ms for the "BO Sarmiento de Gamboa" (Table VI) which is coherent with the RTT obtained from PING. Values for "BIO Hesperides" are 0.5 ms corresponding to an answer made by the server inside the same LAN. This anomaly is due to the action of the accelerator in the Land Site which sends the answer to SYN petition, improving TCP communications in this way.

TABLE VI. RTT VALUES USING HPING3 INJECTING SYN PACKETS TO ON-BOARD WEB-SERVER 80 PORT.

	BIO Hesperides	***BO Sarmiento de G.***
RTT	0.5 ms	734 ms

TABLE VII. CONCLUSIONS

After the optimization of equipment configuration and network parameters on VSAT links of both vessels, communication level is suitable with the current contract. Stable links have been obtained for web navigation and VPN communication.

Accelerators reduce jitter values, and MTU optimization improves the observed asymmetry between the uplink and downlink regarding this parameter.

With repect to throughput both link senses are shown to be symmetric in optimal conditions. The action of accelerators is notable onboard the "BIO Hesperides" to reach the contractual values.

MTU optimization is quite important to reduce packet loss on both vessels. The action of accelerators is indispensable on the "BIO Hesperides".

Changes introduced by the optimizations are not significant over median RTT but can reduce extreme values.

The right selection of hardware is fundamental for successful implantation of this kind of communication systems to guarantee the quality of satellite links and for administrating the particularities of TCP/IP protocols for these links.

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