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Analysis of JANUS and underwater telephone capabilities and co-existence

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Abstract—This document aims at offering a concise look into the co-existence of Underwater Telephone and JANUS digital communication methods. This topic is of particular interest as both methods (one a well-established STANAG and the latter in the process to become a STANAG) have partially overlapping frequency bands. The two techniques are briefly described and the specific interference mitigation strategies built-in in JANUS are presented.

The document then focuses on a series of experiments conducted during the REP14-Atlantic sea trials. These experiments had two main objectives: 1) Measuring the impact of an interfering JANUS signal on the intelligibility of voice messages and 2) assessing the capabilities of both techniques under similar conditions and validation of the JANUS Medium Access Control scheme. Experimental setup, analysis and results are presented for the different activities.

I. INTRODUCTION

CMRE has been developing, testing and promoting JANUS - a simple digital modulation and coding scheme for underwater communications to be used as a baseline enabler for a first degree of (currently non-existent) digital interoperability at the physical layer. JANUS is deliberately simple and designed to be used on so-called “hardware of opportunity”. To enable the use of built-in underwater telephone (UT) transducers, JANUS’ initial frequency band (additional bands are expected to become a part of future versions of the standard) partially overlaps that of the legacy analogue underwater telephone systems.

In order to assess the impact of such overlap on the intelligibility of UT communications, an experiment was prepared by CMRE with the collaboration of the Portuguese (PRT) Navy and WTD 71 (DEU).

Section II briefly describes both (UT and JANUS) techniques, and provides the motivation for this study. Section III describes the experimental setup, while results are presented in Sections IV and V. A discussion on the findings is provided in Section VI.

II. JANUS AND THE UNDERWATER TELEPHONE

The analogue UT was standardised in STANAG 1074 [1] for NATO and cooperating navies. Meanwhile, the specification of UT was transferred into STANAG 1475 [2] as submarine rescue equipment. This specifically addresses the critical safety role of the UT in assisting distressed submarines (DISSUB).

The underwater telephone is a very simple standard, specifying the modulation of voice into a carrier by Upper Single Side Band modulation with 2.7 kHz of analogue bandwidth, approximately that offered by a regular telephone and sufficient to convey speech.

JANUS, on the other hand, is in its essence a digital modulation and coding scheme that provides a physical layer specification for encoding information, of any type, in digital form over a specified frequency. The JANUS standard, specified in [3] and available in condensed form in [4], employs a Frequency-Hopped (FH) Binary Frequency Shift Keying (BFSK) [5] selected for its robustness and simplicity of implementation.

The choice of the initial frequency band for JANUS comes partially from the attractiveness of the 8-14 kHz band for a range of typical communication operational scenarios [6]. Additionally the existence of a number of devices operating in the same frequency band opens the door for the use of “hardware of opportunity” and the possibility to explore the use of JANUS to achieve interoperability among several proprietary solutions.

There are several mechanisms built in JANUS to mitigate for the frequency overlap with the UT, namely:

Partial frequency overlap The bands of the UT and the initial specification of JANUS don’t fully overlap. On the baseband frequency of the signal available at the demodulated output of the UT, i.e. the output that drives the operator’s headset there is more than 1 kHz of “clean” spectrum available at the lower end of the band for voice, - where typically most speech energy is concentrated [7].

MAC The Medium Access Control (MAC) mechanism component of JANUS was specifically introduced to minimise the risk of collisions between JANUS and the UT, always offering precedence to other energy sources occupying the same frequency band, where UT communications can be found. Any energy-based MAC implementation suffers from one drawback: Due to the slow speed of sound propagation, a JANUS transmitter following the specification could be probing the channel while a distant UT transmitter already started sending a message. The energy from this analogue message will arrive at the JANUS transmitter only after it has started its transmission.

Channel reservation The JANUS specification includes a built-in mechanism that allows participating nodes to reserve channel time. This means that with a basic JANUS packet, JANUS-compliant systems can silence neighbouring JANUS transmit-
ters for a period of up to 10 minutes. To invoke the reservation of the channel, a node needs to be able to send JANUS messages with the correct bit flags and reservation time encoded in the field as per the protocol specification.

A natural concern was that the adoption of JANUS could impact the intelligibility of the analogue UT signal in the case where a collision occurs at a receiving system. In order to assess the impact of such overlap on the intelligibility of underwater telephone communications, a series of experiments were prepared and conducted.

III. EXPERIMENTAL SETUP

In order to assess the overall performance of analogue voice systems in the presence and in respect to JANUS, a series of experiments was performed during the REP14-Atlantic sea trial. This trial was organised by CMRE, the PRT Navy and the Faculty of Engineering of the University of Porto (FEUP) and had a wide scope of experimentation. The relevant activities for this document occurred between 5th and 11th of July 2014 off the coast of Portugal. CMRE employed the NATO Research Vessel NRV Alliance and the PRT Navy employed the U-214 class submarine NRP Arpão. The main equipment used included UT devices on board the NRV Alliance and the NRP Arpão, as well as wide band audio recorders and JANUS band transmitters. The setup of the experiments is depicted in Fig. 1. All underwater telephone transmissions were triggered from the NRP Arpão with pre-recorded sequences injected directly into the UT communications equipment.

In the weeks preceding the experiments, an experienced Navy officer (of Italian nationality) recorded the phonetic codes (symbols) <Alpha> to <Zulu> as if he was speaking to a UT unit. The recorded sound file was then segmented (one segment per phonetic code) and re-arranged into randomly generated test sequences consisting of a preamble and 3 phonetic symbols (3 letter codes - 3LC) in the following arrangement:

"The Message is" + <symbol 1> + <symbol 2> + <symbol 3>

The segmentation and randomisation allowed control of the experiment at the transmission side, guaranteeing phonetic consistency (always the same <alpha>, etc.). The randomisation was enforced to remove any biasing effect during auditory tests.

The JANUS interfering signal was of varying intensity to provide a diverse data set. Additionally the repetition interval of the interfering signal was twice the repetition interval of the voice transmissions from the NRP Arpão so we could collect data with and without JANUS interference in a way that would allow us to keep track of the channel conditions.

Since the objective of the experiment was to evaluate the impact of an interfering JANUS signal on the intelligibility of a voice transmission, in worst case scenarios, neither of the JANUS built-in mitigation strategies (MAC and channel reservation) was used.

In order to gain a quantitative assessment of performance comparison between digital and analogue communication ca-

![Diagram](image)

Fig. 1: Experimental setup, with JANUS interfering source on board the NRV Alliance

pabilities we prepared a second set of experiments where UT and JANUS messages were continuously transmitted from the NRP Arpão and recorded on board the NRV Alliance. The NRP Arpão’s UT arbitrary waveform transmission functionality was used to send a pre-generated JANUS message. The JANUS digital waveform was loaded into the NRP Arpão’s UT and the operator would switch back and forth between analogue voice and digital transmission. Due to this way of operation it was not practical to use pre-recorded sequences as had been done for the interference tests. Instead, a script of randomly generated 7 phonetic symbol sequences was followed by the submariners. Randomisation was again applied to eliminate possible listening bias. The length of the voice message (7 letters) was calculated to carry the same amount of useable information as a basic JANUS packet. Since the available “net” user bits in a baseline JANUS packet is 33 (the portion of the application data block), the length of the voice sequences was calculated to provide the best approximation to the quantity of information. While 33 bits can generate $8.58 \times 10^3$ different packets, 7 letters can generate $26^7 = 8.03 \times 10^9$ different combinations.

IV. INTELLIGIBILITY ANALYSIS

Speech intelligibility (SI) - which can be considered as a measure of the probability of understanding speech - can be described as a function of SNR. It typically starts at zero for low SNR values, i.e. if the noise is too strong compared to the speech signal, nothing may be understood. For higher SNRs, the SI rises up to a value near to 1, i.e. if there is no noise, the speech signal is easy to understand. Extensive research on that topic exists with some examples shown in [8] and [9]. An introduction to intelligibility as well as a discussion of the SI function can be found in the chapter 4 of [10].

The auditory tests consisted of playing back received voice messages to listeners under controlled conditions. The listeners recorded the perceived symbols. An error analysis of the listening results was done by simple comparison of transmitted and received symbols. A word (group of 3 letters) is considered as a word error event (WEE), if at least one of its three symbols was not correctly understood (WEE = 1 for an erroneous word, WEE = 0 for an error-free word). Word errors are applied instead of symbol/letter errors because 3LC are in
operative use, i.e. what really matters is the word error rate, not the symbol error rate. By averaging WEEs by listening samples, evaluated by different listeners and equivalent SNR, one can calculate a word error probability (WEP) estimate relative to the SNR. In order to evaluate the impact of JANUS on the intelligibility, the impact of other degradations on the voice signal (e.g. environmental noise, ship noise, marine mammals, reverberation) have to be determined. This is done by evaluation of the voice messages without interference.

The level of interference is quantified by its power over a 1 kHz band. The estimation of the power of the voice signal $P_S$, interference (JANUS signal) $P_I$, and noise $P_N$ is visualised in the spectrogram in Fig. 2. For their estimation the break in the voice signal after the preamble is exploited. The energy of voice signals is concentrated at the frequency range below 1 kHz. Accordingly, the average power of the voice signal (the pronounced letters) is approximated by the energy of the area marked with $P_S$ in Fig. 2. The average power is computed for each transmission event by summing the values in the power density spectrum (PSD) computed by the FFT of the samples in the recording.

$$x[n] = \text{FFT} \left( x \left[ \frac{t_{\text{start}}}{f_s} \right] \ldots x \left[ \frac{t_{\text{stop}}}{f_s} \right] \right)$$

(1)

$$P_S = \sum_{n=\left\lfloor \frac{t_{\text{start}}}{f_s} \right\rfloor}^{\left\lceil \frac{t_{\text{stop}}}{f_s} \right\rceil} |x[n]|^2$$

(2)

$$\text{SNR} \approx \frac{P_S}{P_N}, \quad \text{SIR} \approx \frac{P_S}{P_I}$$

(3)

The intelligibility values presented here were generated from auditory tests based on 420 different voice messages, of which approximately 50% were impacted by a JANUS signal. The samples were grouped in SNR intervals of 3 dB, in 7 test variants of 30 samples with, and 30 without interference. An overall number of 3000 listening events were generated and presented to 50 listeners.

Figure 2 shows the results of the SI curve fitting. The values are averaged over voice samples within -20 dB $<$ SIR $<$ -10 dB. This being the range that contained the most listening samples affected by interference. One can point out the relatively small number of observation points and a much poorer fit of the SI function in the JANUS-interfered data set. In any case it does seem that for the given range of the SIR the intelligibility is limited by the interference. According to the SI function the degradation by interference is about 1/3 or a reduction of 33%. Because of the aforementioned distribution of the SNR of the recorded speech events, it was not possible to gain reliable intelligibility curves from the test results for other SIR ranges.

In [11] the authors propose a modelling technique to expand the intelligibility analysis for additional SIRs.

V. ANALOG VS. DIGITAL ANALYSIS

In terms of efficiency, one baseline JANUS packet at the initial frequency band specification is 1.1 seconds long while the average transmission time for the 7 letter code messages was 16.1 seconds (averaged from 119 transmissions). A selection of recordings was hand-picked from the pre-data analysis to offer a mix of conditions of SNR and relative motion. Figure 4 presents detailed plots of distance between assets (The transmitter NRP Arpão and the Receiver NRV Alliance) and SNR calculated by the JANUS receiver vs. time. The SNR line is a smoothed fit to the cloud of points representing JANUS decoding failures and successes. Highlighted in the plots are the periods selected for auditory tests that were performed by a group of 10 non-trained civilian personnel. Table I presents the decoding results for UT and JANUS packets. These results are segmented in terms of nationality of the listener to point out the “nationality bias” observed. It’s important to recall that these 7 letter messages were transmitted “live” (without pre-recordings, unlike the interference tests) by different PRT Navy submariners. There is an interesting feature in the middle plot of Figure 4, where for high SNRs no JANUS decodings were possible. A first inspection on the audio files of the UT
recordings revealed practically indecipherable words. This will need to be investigated further.

VI. CONCLUSIONS

As expected, high levels of partial overlapping spectral content may impact the ability to correctly “decode” the UT voice messages. It is interesting to observe though that such impact occurred on higher SNR conditions and that the drop of intelligibility was observed for SIR between -10 and -20 dB, i.e. interfering signals between 20 and 10 dB above the voice level.

It can be argued that nodes separated by a high SNR channel are also within the expected normal operating conditions of the proposed MAC and should be able to decode channel reservation requests. Existing underwater telephone equipment could, in principle, implement automated JANUS channel reservation messages triggered by pressing the push-to-talk button (activating a JANUS transmitter system). A digital capability would need to be added to the equipment for this to be achieved.

Other existing techniques employed by equipment currently on the market, where frequency sweeps are used, offer a much more disruptive interference (anecdotal evidence from experience at sea) and their use cannot be prevented nor regulated. It could be controlled if those systems were to become JANUS compliant.

There is clearly a balance of pros and cons in having JANUS partially sharing the UT band. In summary we can point out: Pros: Open way for interoperable digital DISSUB operations with potential for automated transmission of digitally encoded critical data without the need of an operator. Such data could be automatically relayed by other compliant equipment; Create additional protection of the UT against other transmissions in band, by implementing the JANUS MAC on all JANUS compliant equipment; Avoid analogue symbol bias, operator bias. Cons: Potential for impact in intelligibility (up to 30% drop) in specific conditions of high SNR, very low SIR and unfavourable geometries for the energy detection MAC. This could be critical if a distressed submarine with non-JANUS UT equipment meets this specific case.

From what was observed, in case of messages that map information into a limited alphabet (like the phonetic codes), JANUS could replace the UT with considerable advantages.

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REFERENCES


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**Keywords**

Interference, signal to noise ratio, speech, silicon, transmitters, decoding, encoding

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