Deliverable D1.26
Training Sequence for VDES Communications Synchronisation

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Authors

Name	Organisation
Arunas Macikunas	Waves in Space Corp. 2017

Document History

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0.2	14.12.2017	NW	Final Task leader review
0.3	18.12.2017	SD	Final version in E2 template
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Review

Name	Organisation
Bjorn Pedersen	DMA WP.1 Lead
Nick Ward	IALA
Thomas Christensen	Ex-DMA
Ann Lemming	DMA WP.1

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Contents

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Introduction

This report describes work performed in support of IALA ENAV Committee WG3 on development of a VDES standard for both terrestrial and satellite VDE services.

Approach

The experimental approach taken for the investigation of the VDES training sequence is to compare in detail the baseline VDES standard 27-symbol sequence to the predecessor AIS sequence and a number of recommended and known superior training sequences developed for other wireless systems. Dr. Tim Dyson from Harris Corp. started some of the analysis and showed some promising early results of some new sequences in summer 2016 but did not make any thorough comparisons with VDES or AIS sequence performance. This investigation used the VDES standard and analysis routines provided by Dr. Dyson as a starting point to investigate the merits of various training sequence schemes, and to optimize and develop new and superior schemes if possible. The first part of the activity was to develop the comparison metrics, and then to run the analysis on different training sequences to assess their relative performance. The results of the analysis and performance comparisons would be compiled and ranked, and then used to select and justify the selected scheme as a superior training sequence to IALA ENAV Committee WG3 for the VDES standard going forward.

Background

The current VDES standard ITU-R M.2092.Rev0 utilises a dual Barker training sequence for the purposes of identifying the start of a new message packet for every VDES message (packet) transmitted. The VDES training sequence was not carefully optimised during its inception, and is 27 symbols long, somewhat longer than that of AIS at 24 symbols, but cannot be combined with other fixed features in AIS packets, such as the start flag, effectively making the AIS training sequence 32-symbols long. The VDES training sequence also has undesirable correlation properties such as spurious correlation peaks, and moreover, degrades rapidly over high Doppler shift, such as experienced for planned VDE-SAT services.

Tasks Performed

1. Gather background documentation, and a new training sequence detection method suggested by Dr. Krzysztof Bronk.
2. Develop a number of training sequence performance evaluation methods and metrics, such as peak sidelobe ratio, or probability of false detection, and rank the performance metrics based on feedback from IALA ENAV WG3 June 2017 meeting.

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3. Test existing simulation and analysis and find missing elements from Dr. Dyson's Matlab reference.
4. Develop analysis methods for new performance evaluation metrics, such as integrated sidelobe ratio, ambiguity diagram, peak waveform timing estimation error, receiver operation characteristic (ROC), with probability of correct detection and probability of false detection (false alarm).
5. Create computer software models of all sequences to be compared, including the AIS training sequence (over 10 in total), and also:
    a. Create an analytical implementation of the new Dr. Bronk's receive correlator method for the VDES standard training sequence based on discussions, and formula provided by Dr. Bronk.
    b. Create an analytical model for new sync sequence and detection method developed by Space Norway (1st part completed, 2nd part for detection method not completed due to lack of sufficient information on the method from Space Norway).
    c. Develop a correlation receiver for the baseline dual Barker scheme with only a single 13-symbol Barker sequence as a shortened training sequence detection method.
6. Run performance evaluations of all training sequence options, over timing error and full satellite range of frequency uncertainty due to Doppler shift, also including the impact of waveform shaping factor on the pi/4 QPSK VDES baseline modulation scheme.
7. Create tables with figures of merit, create graphical ambiguity plots, and other graphical representations of the analysis results.
8. Compile results above with best ranked schemes according to the metrics evaluated and recommended by IALA ENAV WG3 into final presentation to ENAV20.

Findings

All previously considered and suggested training sequences were evaluated for performance, including some new modified versions of existing sequences against a number of detailed performance metrics. The evaluation considered the best performance in a situation that is representative of a terrestrial-only VDES system (lower propagation delay variation, narrow Doppler variation), and for satellite VDES with higher Doppler variation and considerable propagation delay spread.

At low Doppler offsets, it was found that the baseline VDES dual-Barker training sequence in ITU-R M.2092.Rev.0 is quite weak in many regards, such as both peak and integrated

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sidelobe ratio (so-called ambiguities). A slightly modified version suggested by the author (dual reversed Barker) improved these two metrics by nearly double the number dB, such as peak sidelobe level dropping from a high -6.7 dB to -14.1 dB. Other schemes also achieve performance close to this level at about -13 dB, but even better integrated sidelobe levels were possible, for example using the Chu sequence, a Polyphase Barker sequence or the Dr. Bronk correlator.

Over wide Doppler, as for satellite VDES (VDE-SAT), the Chu sequence was superior to both the ITU-R M.2092.Rev.0 default sequence, as well as the Polyphase Barker (i.e. better in every respect). Unfortunately, the Dr. Bronk correlator did not perform well at higher frequency offset as above and was not a viable alternative. Shaping factor was found to have a similar detrimental effect on all sequences (for which pi/4 QPSK was used), with small and narrower factor causing increased peak sidelobes, say at 0.25, and better as shaping factor was set to default 0.30 and better still at 0.35. Unfortunately, shaping factor of 0.35 causes worse spectral control, and a factor of 0.30 has been selected as baseline for ITU-R M.2092 as a result.

From the ROC (detection and false detection) standpoint, some of the newer sequences suggested did much better at low signal to noise ratios (Es/No = -6 or -3 dB), for example Chu sequence achieved PD of 46% at -6 dB SNR, while 2092 Barker only achieved PD of 22%, while polyphase Barker and Zadoff-Chu were also superior to the baseline 2092 sequence.

One important finding was that there was not a sequence that was uniquely better for terrestrial VDES and one for satellite. It turns out that the Chu sequence or polyphase Barker was superior to the baseline sequence and most other sequences under all conditions.

The recommendation was made at the ENAV20 meeting to adopt a revised training sequence for VDES, **specifically the CHU 27 symbol long sequence**, but due to the lack of consensus among those attending on the need for better performance, and the complaints from several vendors already invested in implementing the ITU-R M.2092.Rev0 method, no agreement to change the scheme was reached.

Primary Deliverables

D.1.26 This report, Training Sequence for VDES Communications Synchronisation.

D.1.26A Presentation on VDES Training Sequence Performance Characteristics given by Dr. Macikunas to IALA ENAV20 in June 2017.

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D1.26B Updated and final presentation on VDES Training Sequence – Performance Characteristics (v.1.2) given by Dr. Safar (GLA R&RNav) at ENAV21 in September 2017.

D1.26C Updated MATLAB analysis code, Training Sequence Study VDES Evaluation Code Arunas18Aug2017, provided to Dr. Jan Safar.

Acronyms

AIS	Automatic Identification System
GLA	General Lighthouse Authorities of UK and Ireland
QPSK	Quadrature phase shift keying
ROC	Receiver operation characteristic
TDL	Tapped delay line
VDES	VHF Data Exchange System
VDE-SAT	VHF Data Exchange Satellite link

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