Input paper: [[1]](#footnote-1) ENAV22-9.2.12

Input paper for the following Committee(s): check as appropriate Purpose of paper:

**□** ARM **□** ENG **□** PAP **X**  Input

X ENAV  **□** VTS **□** Information

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Technical Domain / Task Number 2 Working Group 2 (Digital Communication system)

Author(s) / Submitter(s) KIM Wonyong (COMESTA)

KIM Juntae (Korean Register)

Analysis of the effect of short training sequence (Syncword)   
on Bit Error Ratio performance

# Summary

This input paper is to discuss the problem on BER (Bit Error Ratio) performance degradation due to the frequency offset when implementing the physical layer of the receiver of ASM and VDE-TER according to IALA Guideline G1139 Ed.1. The problem on performance degradation caused by short length of training sequence was identified though simulations and the effective frequency offset processing method to solve the problem was reviewed in the paper.

## Purpose of the document

This input paper is aiming to discuss the problem on performance degradation caused by length problem of Training Sequence(Syncword) according to IALA Guideline G1139 Ed.1.

## Related documents

None

# Background

The VDES physical layer is designed by TDMA method and the frame structure of the burst signalling method is used according to ITU-R M.1371-5, in addition, turbo code, CRC-32, bit scrambler, PSK/QAM modulation are used. The following table 1 summarizes the main system parameters of the VDES physical layer.

Table 1. Main system parameters for Link Configuration ID (LCID)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| LCID | Modulation  Type | Syncword Symbols | LCID  Symbols | Symbol Rate  [sps] | FEC  Code rate | roll-off  factor |
| 1,2,3 | PI/4 | 27 | 16 | 9600 | Uncoded | 0.35 |
| 5,6,7 | PI/4 | 27 | 16 | 9600 | 3/4 | 0.35 |
| 8,9,10 | PI/4 | 27 | 16 | 9600 | 1/2 | 0.35 |
| 11,14,17 | PI/4-QPSK | 27 | 16 | 19,200  38,400  76,800 | 1/2 | 0.3 |
| 12,15,18 | 8PSK | 27 | 16 | 19,200  38,400  76,800 | 3/4 | 0.3 |
| 13,16,19 | 16QAM | 27 | 16 | 19,200  38,400  76,800 | 3/4 | 0.3 |

In general, it is expected that the receiver for PSK or QAM can accomplish ideal demodulation performance when demodulated in the condition of achieving signal amplitude stabilization, timing and frequency synchronization. In addition, synchronization algorithms typically for this purpose use some known symbols, which is known both at the transmitter and at the receiver, such as training symbols.

The training symbol used in VDES is named as 'Syncword' and defined as 27 symbols in accordance with IALA G1139 Ed.1. The Syncword is generated by π/4-QPSK modulation with repetition of Syncword sequences as defined in the following table 2, that arranged making use of two kinds of barker code sequences.

Table 2. Syncword Sequences for VDES

|  |  |  |  |
| --- | --- | --- | --- |
| Usage | Symbol Size | Sequence | Type |
| ASM /  VDE-TER | 27 | 1 1111100110101 0000011001010 | 1 + Barker13 +  inverted Barker13 |

# BER Performance Analysis on the method to treat Carrier Frequency Offset

## BER Performance on General Carrier Recovery Algorithm with IALA Guideline G1139

VDES uses π/4-QPSK, 8PSK and 16-QAM modulation methods according to the IALA G1139 Ed.1, but these kinds of modulation methods are sensitive to frequency offsets, therefore, it should be designed with coherent receiver which applying CR (Carrier Recovery) algorithm for the estimation and compensation of frequency offsets.

The operational goal defined in IALA G1139 Ed.1 is the maximum frequency offset of 500 Hz. In addition, Syncword 27 symbols are defined as the training symbols for performing CR function.

Since the frequency offset of 500 Hz is the large value corresponding to 5.21% (ASM) in comparison with the symbol rate, it is not easy to perform the CR function using the Syncword of 27 symbols. Generally, CR is composed of the coarse CR to handle a wide frequency offset and a CR tracking to track a narrow range of residual frequency offset as shown in Figure 1.



Figure 1. Components for Carrier Recovery Algorithm

The below table 3 includes the analysis for the required SNR in order to achieve BER of and shows the performance under the frequency offset of 500 Hz for the receiver employing the general carrier frequency recovery algorithm in accordance with IALA G1139 Ed.1.

Table 3. BER Performance with General CR

|  |  |  |  |
| --- | --- | --- | --- |
|  | with Coherent  Ideal sync. | with General CR | Performance degradation with CR via ideal sync.  (Gap for required SNR)  [dB] |
| LCID (MCS) | Required SNR[dB]  @ BER= | Required SNR [dB]  @ BER= |
| 05 (π/4-QPSK 3/4) | 6.2 | 10.2 | 4.0 |
| 06 (π/4-QPSK 3/4) | 5.6 | 10.4 | 4.8 |
| 07 (π/4-QPSK 3/4) | 5.5 | 10.2 | 4.7 |
| 08 (π/4-QPSK 1/2) | 3.5 | 10.3 | 6.8 |
| 09 (π/4-QPSK 1/2) | 3.7 | 10.6 | 6.9 |
| 10 (π/4-QPSK 1/2) | 2.3 | 10.8 | 8.5 |
| 11 (π/4-QPSK 3/4) | 3.0 | 11.1 | 8.1 |
| 14 (π/4-QPSK 3/4) | 2.3 | 10.8 | 8.5 |
| 17 (π/4-QPSK 3/4) | 1.9 | 9.8 | 8.9 |
| 12 (8PSK 3/4) | 9.9 | 16 | 6.1 |
| 15 (8PSK 3/4) | 9.4 | 16 | 6.6 |
| 18 (8PSK 3/4) | 9.4 | 16 | 6.6 |
| 13 (16-QAM 3/4) | 11.8 | 15.3 | 3.5 |
| 16 (16-QAM 3/4) | 11.5 | 16.2 | 4.7 |
| 19 (16-QAM 3/4) | 11.5 | 16.1 | 4.6 |

Simulation result shows that the required SNR to satisfy with BER of is degraded in drop of 3.5 ~ 8.9dB in comparison with coherent ideal synchronisation when using a general carrier frequency recovery algorithm. It is considered difficult to implement the receiver with the general carrier frequency recovery algorithm.

## BER Performance on General Carrier Recovery Algorithm with increasing the Number of Training Symbols

The number of training symbols is important for a general carrier frequency recovery algorithm. However, the number of the training symbols defined in IALA G1139 is 27, but which is short and considered not sufficient to process frequency offset of 500Hz.

In this section, the BER performance is analysed to check the required number of training symbols capable of processing frequency offset 500 Hz when applying general carrier frequency recovery algorithm.



Figure 2. BER Performance with Number of Training Symbols (for LCID#08)

The below table 2 shows the required SNR to achieve BER of per the number of training symbol from the above graph in Figure 2.

Table 4. Required SNR with Number of Training Symbols (for LCID#08)

|  |  |  |  |
| --- | --- | --- | --- |
| Number of Training Symbols | Required SNR [dB] @ BER = | Data Rate (Uncoded)  [kbps] | Note |
| π/4-QPSK TC 1/2 |
| 27 | 10.3 | 14.775 | Defined in G1139 |
| 50 | 8.2 | 13.050 |  |
| 75 | 7.4 | 11.175 |  |
| 100 | 6.8 | 9.300 |  |
| 120 | 6.5 | 7.800 |  |
| 140 | 5.8 | 6.300 |  |
| 160 | 5.5 | 4.800 |  |
| 170 | 5.0 | 4.050 |  |

The above table 4 shows that the required SNR to achieve BER of is 3.5dB in the condition of ideal synchronization, the total required SNR is 5dB if a typical implementation margin of 1.5dB is added. As the result of the simulation, the number of training symbols satisfying with the target SNR of 5dB is identified to be about 170. In this case, the payload data rate is 4kbps which is significantly lower than the payload data rate of 14kbps when using 27 training symbols.

## Differential Modulation

This section analysed the performance of the differential modulation scheme capable of effectively handling the frequency offset while maintaining the data rate whilst it differs from the modulation scheme specified in the IALA G1139 Ed.1.

The following table shows the required SNR to achieve a BER = per each LCID for the differential modulation scheme with 27 training symbols under a frequency offset of 500 Hz.

Table 5. Required SNR on Differential Modulation

|  |  |  |  |
| --- | --- | --- | --- |
|  | with Coherent  Ideal sync. | Result applying the differential modulation | Performance Degradation  at differential modulation  (Gap for Required SNR)  [dB] |
| LCID (MCS) | Required SNR [dB]  @ BER= | Required SNR [dB]  @ BER= |
| 05 (π/4-QPSK 3/4) | 6.2 | 9.3 | 2.9 |
| 06 (π/4-QPSK 3/4) | 5.6 | 8.8 | 3.2 |
| 07 (π/4-QPSK 3/4) | 5.5 | 8.8 | 3.3 |
| 08 (π/4-QPSK 1/2) | 3.5 | 6.6 | 3.1 |
| 09 (π/4-QPSK 1/2) | 3.7 | 6.7 | 3.0 |
| 10 (π/4-QPSK 1/2) | 2.3 | 5.8 | 3.5 |
| 11 (π/4-QPSK 3/4) | 3.0 | 6.4 | 3.4 |
| 14 (π/4-QPSK 3/4) | 2.3 | 5.5 | 3.2 |
| 17 (π/4-QPSK 3/4) | 1.9 | 5.1 | 3.2 |
| 12 (8PSK 3/4) | 9.9 | 13.2 | 3.3 |
| 15 (8PSK 3/4) | 9.4 | 12.7 | 3.3 |
| 18 (8PSK 3/4) | 9.4 | 12.6 | 3.2 |
| 13 (16-QAM 3/4) | 11.8 | 16.2 | 4.4 |
| 16 (16-QAM 3/4) | 11.5 | 16.2 | 4.7 |
| 19 (16-QAM 3/4) | 11.5 | 15.8 | 5.3 |

When the differential modulation scheme is applied, the performance in the required SNR is degraded by about 2.9 ~ 5.3dB in comparison with coherent ideal sync method. However, it is checked that QPSK and 8PSK can have better performance than applying a general CR for the receiver in accordance with IALA G1139 Ed.1 under the same receiving conditions.

# Conclusion

In this paper, it is verified that the degradation of BER performance during processing frequency offset is happen due to the lack of number of training symbols when the physical layer of receiver is implemented according to the system parameters defined in IALA G1139 Ed.1. As the result of simulation, BER performance with LCID was founded degraded by about 3.5dB ~ 8.9dB when applying the general carrier frequency recovery algorithm according to IALA G1139 Ed.1. When training symbols is increased accepting the decrease of data rate, it is identified that at least about 170 training symbols should be used in order that the implementation margin can be realized within 1.5dB. In addition, differential modulation method could be applied within the performance degradation range of 2.9 ~ 5.3dB while keeping the data rate.

In conclusion, the problem on degradation caused by short syncword length in IALA G1139 Ed.1 should be discussed in IALA ENAV 22 and the most suitable method to solve this issue should be reviewed and reflected in IALA G1139 as appropriately.

# References

1. IALA Guideline G1139, The Technical Specification of VDES, Working Draft, 20180117 - ESTEC Intersessional, Edition 1.0

# Action requested of the Committee

The Committee is requested to note the information and take appropriate action.

1. Input document number, to be assigned by the Committee Secretary [↑](#footnote-ref-1)
2. Leave open if uncertain [↑](#footnote-ref-2)