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Abstract: *We study inter-channel interferences in VHF transmissions for the maritime automatic identification system and propose solutions to avoid them. The inter-channel interference is caused by the brevity of SOTDMA frames used by ships to transmit their position. In order to avoid the spreading of the spectrum, two solutions are considered. A Tukey window is first used to avoid a too hard transition between consecutive temporal slots. The second solution consists in using a Chebyshev lowpass filter. We compare these two solutions in term of interference and show that their association can be envisaged with reasonable complexity.*

Keywords: AIS system, VHF transmissions, SOTDMA, inter-channel interference, Chebyshev lowpass filter, Tukey window

1 INTRODUCTION

In order to make safe maritime traffic, the International Maritime Organization (IMO) recently published a standard [1] for Automatic Identification System (AIS). Such systems use GPS to allow ships to communicate each other their respective position, thus avoiding risks of collision. Two Very High Frequency (VHF) channels and a Gaussian Minimum Shift Keying (GMSK) modulation are used, and the ships transmissions are organized by the Self Organized Time Division Multiple Access (SOTDMA) technology.

In practice, however, AIS receivers are very sensitive and the brevity of ships transmissions causes inter-channel interference (ICI). This paper studies the impact of such interference on neighboring frequencies and proposes efficient solutions to limit those negative effects. In order to avoid a brutal transition between two consecutive slots, we propose to use a Tukey window. Indeed, this window does not affect the signal in its central temporal part, but only at its extremities. The second solution considered in this paper is a Chebyshev lowpass filter. This filter must not modify the signal in the AIS band and its order must be low enough because of the delay it implies at the receiver. Finally the association of the two solutions is considered and comparisons are performed to evaluate the best compromise.

2 DESCRIPTION OF THE AIS SYSTEM

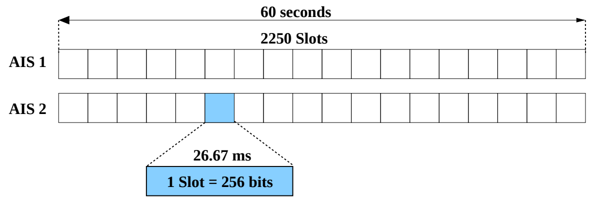

Figure 1: AIS frame organization in TDMA mode

The modulation used in the AIS system is a GMSK modulation with a modulation index *h=1/2* and a product *BT=0.3* or *BT=0.5*, where *T* is the bit duration and *B* is the -3dB cut-off frequency of the Gaussian filter.

Using Laurent decomposition, the complex envelope can be approximated [2] by Pulse Amplitude Modulation (PAM) signal

$$s(t) = \sum_{k=-\infty}^{\infty} c_k c_0(t - kT) \quad (1)$$

with $c_0(t)$ the most significant Laurent function and $c_k = \exp(j\pi h \sum_{n=-\infty}^{k} a_n)$ where a_n are symbols +1 and -1 corresponding to binary data (the data rate is $F_d = 9600$ Hz). The AIS system uses two channels AIS1 and AIS2, respectively at frequencies 161.975 MHz and 162.025 MHz, with a bandwidth of 25 kHz.

To organize transmissions of every ship in an area, the AIS system uses Self Organized Time Division Multiple Access (SOTDMA), with 2250 slots per 60 seconds frame as illustrated in figure 1. Each ship in a considered geographical area uses one or more specific slot(s) to transmit data (position, direction, speed...). The maximum number of consecutive slots (Ncs) for one ship report is 5. The Report Rate RR (number of repeated reports during one frame) for a ship lies between 1/3 to 30, depending on the speed of the ship.

The brevity of such slots results in a spectrum spreading and in inter-channel interference (ICI). This negative effect is illustrated further on Fig. 5 by the comparison between the curves labelled "Theoretical GMSK" (One ship using a continuous GMSK modulation) and "R-GMSK/SOTDMA" (30 ships using the SOTDMA mode). The constant power spectrum level results in ICI to neighboring VHF channels. Note that only the half of the power spectral density of the baseband signal is represented, and the limit of an AIS channel corresponds to the normalized frequency $25/2/9600 \simeq 1.3$.

3 PROPOSED SOLUTIONS

In order to avoid such perturbations, we propose two solutions that can be implemented after the baseband signal as illustrated in Fig. 2. As the spectrum spreading is

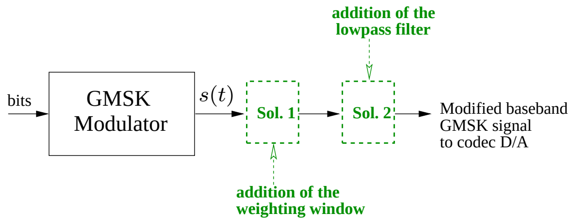

Figure 2: Proposed solutions to avoid AIS interference

mainly due to the hard transitions between slots, a temporal weighting window (Sol.1) can be used to obtain softer transitions. The second solution (Sol.2) consists in using a lowpass filter. This filter must stop the signal apart from $1.3F_d \simeq 12.5$ kHz and its order has to be low because of the delay it induces on the signal. These two solutions can be used separately, but they can also be associated. In this paper only Sol.1 and the association of Sol.1 and Sol.2 are presented.

3.1 Weighting window

A ship can use until 5 consecutive slots, so the window must preserve most of the signal in its central part, and decrease it only at extremities [3]. The Tukey window, which allows to respect these constraints [4] is defined by

$$w(k+1) = \quad (2)$$

$$\begin{cases} 1 & \text{for } 0 \le |k| \le \frac{N}{2}(1+\alpha) \\ \frac{1}{2}(1+\cos(\pi \frac{k-\frac{N}{2}(1+\alpha)}{N(1-\alpha)})) & \text{for } \frac{N}{2}(1+\alpha) \le |k| \le N \end{cases}$$

with N the number of points of the window and α the transition parameter. For the extreme cases, we obtain a rectangular window ($\alpha = 0$) and a Hann window ($\alpha = 1$).

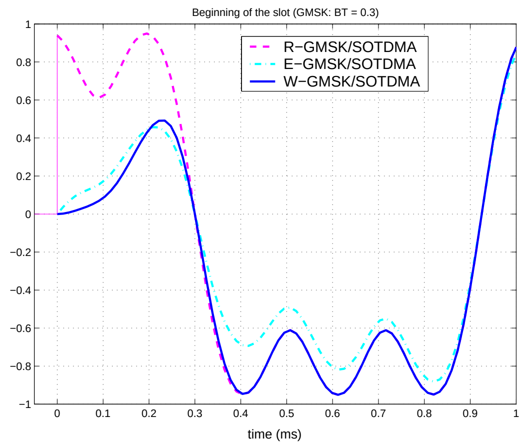

Figure 3: Temporal evolution of the GMSK signal (beginning of the slot) with the weighted window

The choice of α is crucial in this application in order to apply this solution without changing the GMSK receiver. The ITU recommandations for AIS Systems [3] imposes the following temporal constraints :

C.A At the begin of the transmission, the time to establish 80% of the power of the signal must be less than 1 ms.

C.B At the end of the transmission, the signal must achieve the level “zero” in less than 1 ms since the power supply is stopped.

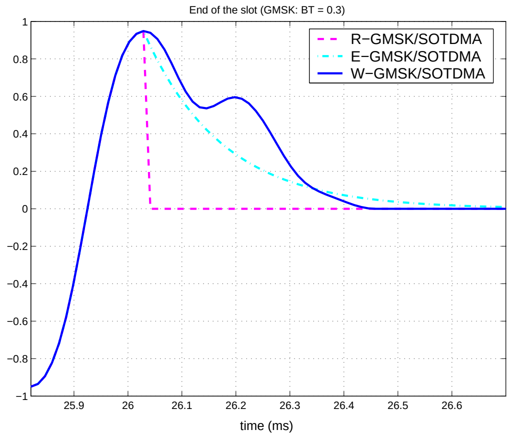

Figure 4: Temporal evolution of the GMSK signal (end of the slot) with the weighted window

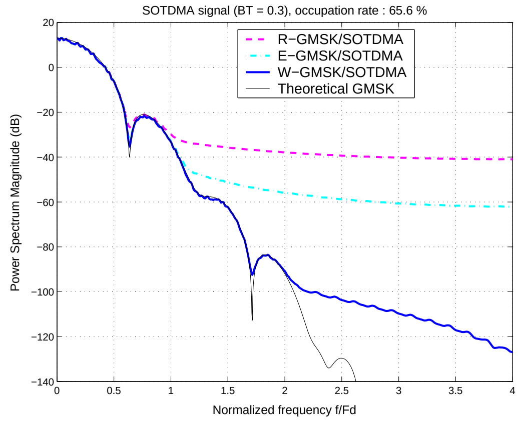

Figure 5: PSD of the W-GMSK/SOTDMA signal

In order to respect these constraints, the parameter α is determined such that the ramp up (and the ramp down) of the window is less than 1 ms. The number P of bits affected by the transition of the window must be then less than 10 bits ($10/9600 \simeq 1$ms).

By defining N_T the sampling factor (number of samples per bit) and $N_P = P \times N_T$, Eq. (2) can be expressed

$$w(k) = \tag{3}$$
$$\begin{cases} \frac{1}{2}(1+\cos(\frac{\pi}{P}(k-N_P-1))) & \text{for } k\text{=}1,\ldots,N_P \\ 1 & \text{for } k\text{=}N_P\text{+}1,\ldots,N\text{-}N_P \\ \frac{1}{2}(1+\cos(\frac{\pi}{P}(k-N+N_P))) & \text{for } k\text{=}N\text{-}N_P\text{+}1,\ldots,N \end{cases}$$

The resulting sampled weighted signal $s_w(k)$ is then:

$$s_w(k) = s(k)w(k) \text{ pour } k = 1, \ldots N \tag{4}$$

Figs. 3 and 4 represent respectively the GMSK signal at the beginning and at the end of the slot with the Tukey window (solution labelled W-GMSK-SOTDMA, cf. Eq. (4)). The number of bits affected by the window is chosen at $P = 5$ ($5/9600 \simeq .52$ms$<$ 1ms). The labels "R-GMSK/SOTDMA" and "E-GMSK/SOTDMA" stand for classical AIS transmissions with rectangular and exponential transitions between slots, respectively. The waveform "E-GMSK/SOTDMA" illustrates the temporal evolution of the GMSK signal by taking into account the constraints C.A and C.B. One should note that in practical situation, the transition of the signal must be a compromise between the rectangular and the exponential waveforms.

Fig. 5 compares the power spectral density (PSD) of the weighted solution (W-GMSK/SOTDMA) to the PSD of the rectangular and exponential waveforms. The PSD are estimated on one AIS frame. The SOTDMA signal corresponds to a scenario with 30 ships (the RR and the number of slots per ship are randomly chosen, and the occupation rate is about 65% of the AIS frame). Outside the AIS channel, a significant constant level of the power spectrum is observed for the classical AIS transmission (R-GMSK/SOTDMA or E-GMSK/SOTDMA). This level can cause interferences on neighboring VHF channels for sensitive VHF receivers (the sensitivity of classical AIS receivers is about -80 dB). This figure illustrates the efficiency of the windowing by the Tukey window. This solution which affects only 5 bits can be easily applied on the GMSK modulator and does not modify the signal for data transmission. The constraints C.A and C.B are respected but the power off of the modified AIS system must be delayed about 0.52 ms (cf Fig. 4) in comparison to the original system. Furthermore, in spite of the efficiency of the Tukey window, inter-channel interference can occur nearby the $1.3F_d$ spectrum area.

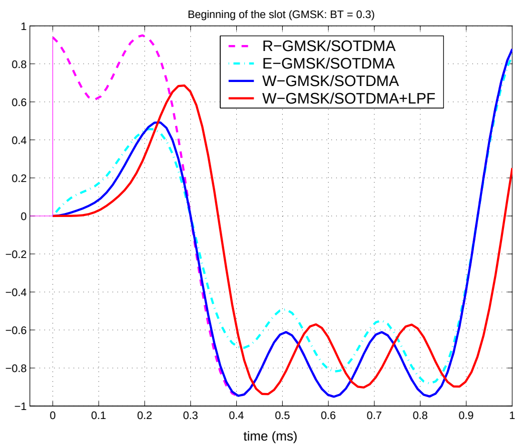

Figure 6: Temporal evolution of the GMSK signal (beginning of the slot)

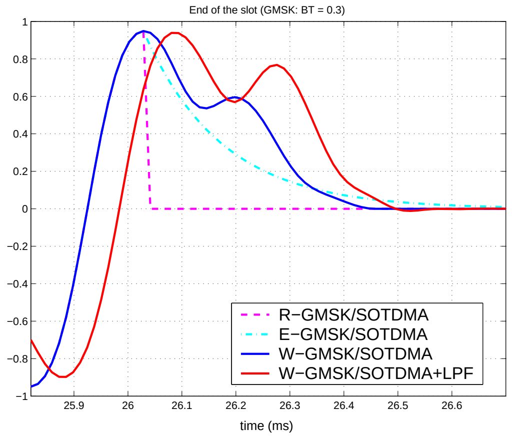

Figure 7: Temporal evolution of the GMSK signal (end of the slot)

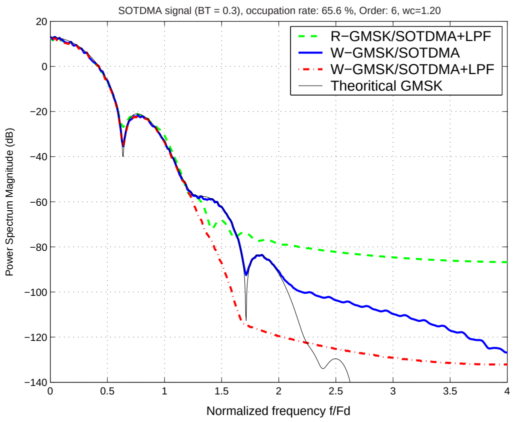

Figure 8: Comparison of the Tukey windowing and the association with the Chebyshev filtering.

3.2 Association with a lowpass filter

In order to improve the interference rejection a lowpass filter can be added after the Tukey window. A good solution seems to be a type 1 Chebyshev filter of order 6. The peak-to-peak ripple in the bandpass is chosen at 0.5 decibels and the cut-off frequency is fixed at $1.2F_d$ Hz.

Figs. 6 and 7 show the transition at the beginning and at the end of a slot. The addition of the lowpass filter delays the signal by about 0.05 ms. The effect of the filter improves the interference rejection for the neighboring frequencies greater than $1.3F_d$ Hz as shown in Fig. 8 (the associated solution is labelled "W-GMSK/SOTDMA+LPF"). One should note that the solution which consists in using only the low pass filter ("R-GMSK/SOTDMA+LPF") is less efficient and is consequently not presented in this paper.

4 Conclusion

We presented in this paper ICI rejection solutions for maritime AIS systems, used by ships to avoid collisions by transmitting their respective positions. These interferences are caused by the brevity of the SOTDMA transmissions which spreads the spectrum on the neighboring VHF channels. This paper presents only theoretical studies and solutions on the ICI problems on AIS systems, but these kinds of solutions may be implemented soon.

The first solution consists in using a Tukey window to avoid hard transitions between consecutive slots. This solution is very simple to implement and suppresses most of the spectrum constant level. The receiver remains unchanged, but the transmitter has to stop with a delay of 0.52ms (5 bits here) with respect to the original system. One should note that this delay is not prohibitive, since it respects the constraints of the AIS standard.

In order to limit ICI more severely nearby the AIS bandwidth limit ($1.3F_d$), a Chebyshev lowpass filter can be added, but this solution implies a modification of the useful signal that must be taken into account by the receiver.

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