A STOCHASTIC MODEL FOR SPACE-BORNE AIS

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The objective of this report is to show how useful stochastic models of AIS signal reception can be constructed to assist in the optimization of space-borne AIS receiver systems. Unlike simulation, which is a complementary technique, these models, based on probability theory, may provide a direct fundamental understanding of the processes that are most important to operational capability.

When both Class A and Class B transmitters are located in a region, the Class B signals are likely to interfere with the desired Class A signals. However, the Class B signals are transmitted with lower power so that, even in the presence of interference, it may still be possible to receive a Class A signal successfully.

A model involving both Class A and Class B transmitters can be developed in several stages. In the first stage we consider a single Class A transmitter in the presence of a number of Class B transmitters scattered uniformly within the receiver antenna beam, which is pointed towards nadir. If signal power and transmitter range effects are neglected, the entire single class A signal will be received successfully if no Class B signal is received during a 256 bit time slot taking a time of τ=26.67 ms (corresponding to a bit rate of 9600 b/s). A collision will occur if the start of the interfering signal occurs over a period of 2τ.

Because of self-organization built into the AIS SOTDMA protocol, there will be an area where signal collisions do not occur. There will be a larger area where the transmitters will be effectively synchronized because their timing relies on GPS and here the collision interval is just τ. At larger distances from the Class A transmitter, propagation delays will cause interference over the full 2τ. The USCG has advocated an average value of 1.7τ to account for these effects.

The stochastic model must also take into account the two AIS channels and the fact that a message can also be received if the message leader and trailer bits are obscured. These features reduce the number of signal collisions and their impact.

Considering the time interval over which a single Class A message may be transmitted, the Class B transmitters represent a potential interference background of emitters that generate signals at random times. The probability distribution of the number of signal starts in a time interval t is Poisson distributed, i.e.

$$P(n) = e^{-\lambda t} \frac{(\lambda t)^n}{n!} \tag{1}$$

where λ is the mean rate of signal starts. In particular, the probability of no signal starts in time t is given by:

$$P(0) = e^{-\lambda t} \tag{2}$$

If the number of ships carrying Class B transmitters is N_B and the mean interval between their transmissions is t_B, the mean rate of transmissions is N_B/t_B. Therefore a reasonable estimate of the probability that there will be no interference with the Class A transmission is:

$$P(0) = \exp\left(\frac{-1.7 N_B \tau}{2t_B}\right) \tag{3}$$

If the signals are received for a time total T and the interval between Class A transmissions is t_A, the number of attempts to receive a signal $M=T/t_A$. No Class A signals will be received successfully if each of the M attempts fails. The probability of a single failure is 1-P(0) and the probability of M failures in succession is this probability raised to the Mth power. Therefore the probability of getting at least one success is given by:

$$P\{Success\} = 1 - (1 - P(0))^M \tag{4}$$

Figure 1, which is based on equations (1) to (4) shows a graph of this probability for the parameters in Table 1; no corrections have been made for Class B range effects or partial interference within the leader and trailer bits.

TABLE 1 AIS Parameters	
Class A and B signal interval (ms)	26.67
Class A transmission interval (s)	10
Class B transmission interval (s)	30
Total time (s)	420

If the effective value of τ is reduced to account for these effects, the position of the 80% probability level changes markedly as a function of the number of ships in the beam. For example, if the effective value of τ is reduced by a factor, F, of 0.6, the 80% level is changed from about 4350 to about 7250.

For the present we are interested only in the successful reception of Class A transmissions. In general there will be a mixture of a number N_A of Class A and a number N_B Class B transmissions. We begin by considering the reception from a single ship with a Class A transmitter. The background now arises from N_A-1 Class A and N_B Class B transmitters. However, the transmissions can still be considered to be random in time so that the distribution is still Poisson and the mean rate λ becomes the mean rate for both classes, which is just equal to the sum of the rates for Class A and Class B:

$$\lambda = (N_A - 1)/t_A + N_B / t_B \tag{5}$$

The probability of the successful receipt of at least one Class A transmission is now:

$$P\{Success\} = 1 - (1 - \exp(-1.7\lambda\tau / 2))^{T/t_A} \tag{6}$$

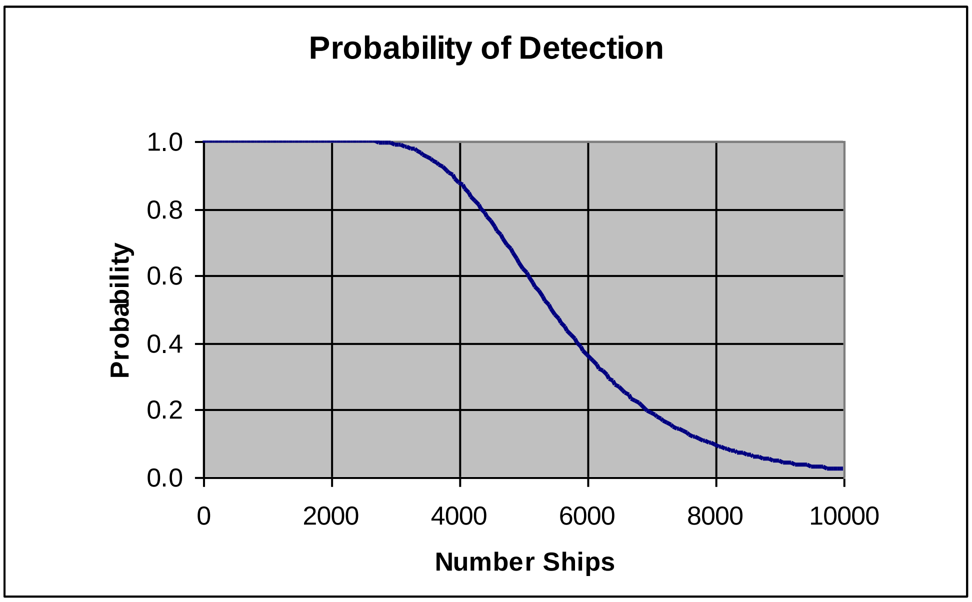

Figure 1. Probability of Detection of Class A Message in Class B environment.

Figure 2 shows the probability of detection of a Class A ship message as a function of the number of ships for a mixture of 50% Class A and 50% Class B ships. No reduction factor is used. However, when τ is reduced by a factor of 0.6, Figure 3 is the result.

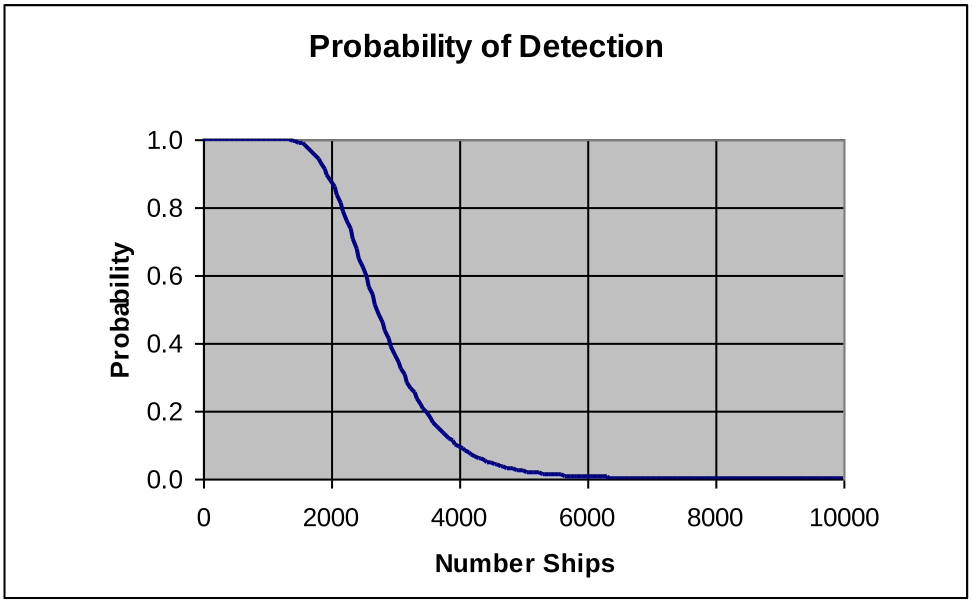

Figure 2. Detection Probability for a 50% Mixture of Classes A and B: F=1.

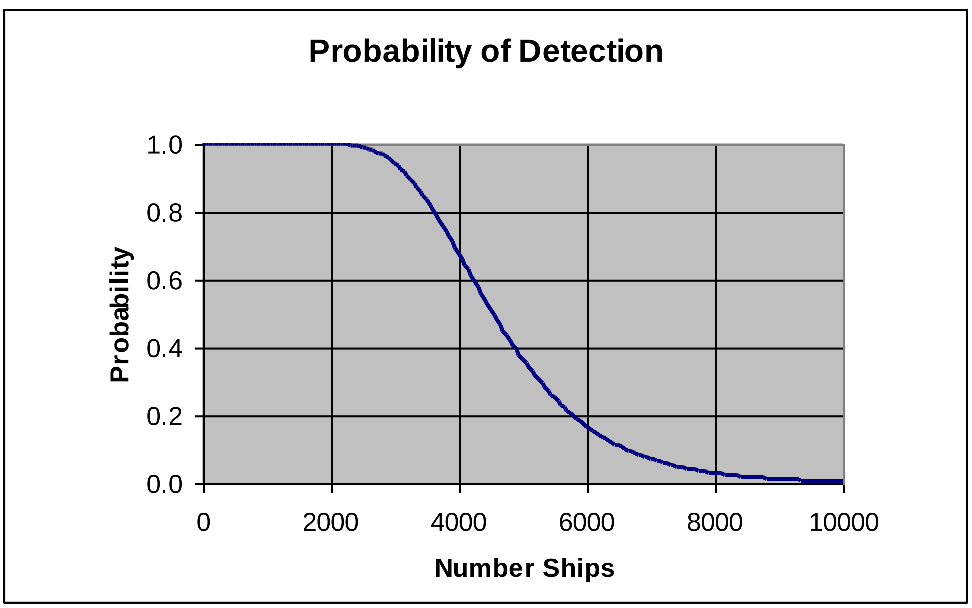

Figure 3. Detection Probability for a 50% Mixture of Classes A and B: F=0.6.

To take into consideration the power of the interfering transmitters we note that a signal failure will occur when the received power from interferers is greater than –10 dB relative to the signal. Class A ships will interfere with one another as before but Class B ships will interfere only when they are sufficiently powerful or when a combination of Class B ship messages has a received power greater than the threshold. The calculation is simplified if the probability of receiving more than a few Class B messages during a Class A transmission time is negligible.

Using the parameters in Table 1 and assuming that there are 2000 Class B emitters over two AIS channels, the mean number of class B collisions, $\lambda\tau$, is about 0.44. From equation (1) it is evident that the probability of getting more than one collision is about 0.07 and more than two collisions is about 0.02. Therefore the main effect through the received power is to limit the area of the beam than can contribute a single Class B collision. In effect, Class B emitters outside of a certain radius from the receiver can be excluded from consideration because the probability that they can contribute enough power to produce a collision is negligible. This justifies the application of another reduction factor, f. To a good approximation, equation (5) can be replaced by

$$\lambda = (N_A - 1)/t_A + fN_B/t_B \qquad (5)$$

where f is based on the threshold of –10 dB, the relative transmitter powers of Class A and B and the satellite and antenna geometry.

When the number of Class B ships is much greater than 2000, it may be necessary to include the effects of more than one contribution to the interference and to generalize the theory.

Conclusion

It appears to be quite feasible to generate useful engineering models of the stochastic processes involved in space-borne AIS signal reception. These can be used to understand the basic processes and provide a clear picture to assist in system optimization. The results presented here seem to be consistent with those of other workers; this includes both theory and simulations described in both the Norwegian and the JSC presentations.

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