# AN ANALYSIS OF AIS SIGNAL COLLISIONS


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The signal collisions that occur when a satellite borne AIS receiver receives the ship transmissions can be analyzed theoretically. Though only full simulations can reveal actual performances, the theory provides an upper limit. Therefore theory is useful for verifying simulation results and for illuminating the essential features that contribute to performance. This report describes a comparison between the theory and the results obtained by the contractor in a recent study.

The essence of AIS receiver performance is not so much the SOTDMA protocol (as claimed by the contractor) but the fact that AIS messages are short and that they are transmitted repeatedly on the one or the other AIS VHF channels. If there is a collision involving the signal from a given ship, then there can be further opportunities for reception of the signal at subsequent times.

In the simplified model adopted here, it is assumed that there are M independent trials or transmissions each from N ships. The value of M is determined by the time that the receiver antenna footprint is over a ship at a fixed point. This is determined by the antenna beam width. The value of N is regarded as a parameter and we seek to estimate the probability that a signal from any given ship will not experience a collision in M trials. To calculate this, the probability is needed that there is a collision during a given transmission from the given ship, with another transmission from another of the remaining N-1 ships. This is found by considering one additional ship at a time.

Even for the simplified stochastic process, the statistical model is not the most appropriate but its accuracy should be adequate for the present purposes and it resembles that used by the USCG.

For simplicity it is also assumed that the time interval of each transmission or “AIS slot”, $\tau$, is fixed and that the time between transmissions, T, is fixed. Thus the number of trials M is equal to the total time a ship is in the antenna beam divided by T.

The probability of the signals from just two ships colliding is denoted by q. The probability that the signals do not collide is p=1-q. When there are N ships, a signal will be received successfully only when there are no collisions from the N-1 transmissions in the trial of interest. The probability of the successful reception from our given ship is equal to $p^{N-1}$.

In M trials, we are interested in the event that there are one or more successful receptions. This is the complement of the event that all transmissions will experience collisions. Therefore the required probability is given by:

$$P\{Number\ of\ Clean\ Signals > 0\} = 1 - (1 - p^{N-1})^M \quad (1)$$

A collision is defined as the event that two transmissions overlap. Without any synchronization, this can occur over a time 2τ within a time T. (Because some signal bits are redundant, the overlap time could be somewhat pessimistic.) With two channels, the probability, q, of overlap within one trial period is:

$$q = 1 - p = \frac{2\tau}{2T} \quad (2)$$

However, the USCG have made a correction to this to account for synchronization and the self-organization of transmissions; they use $q=1.7\tau/(2T)$ but this could still be a little pessimistic.

In the following, the results found by the contractor during their simulations are compared to those generated by the simplified model. For example, the contractor presents the probability that any message is blocked as a function of the number of ships; this is given by $1-p^{N-1}$. Figure 1 shows the probability that a signal is blocked using the methodology and parameters of the USCG with a repeat time of 2 s (30 transmissions per second).

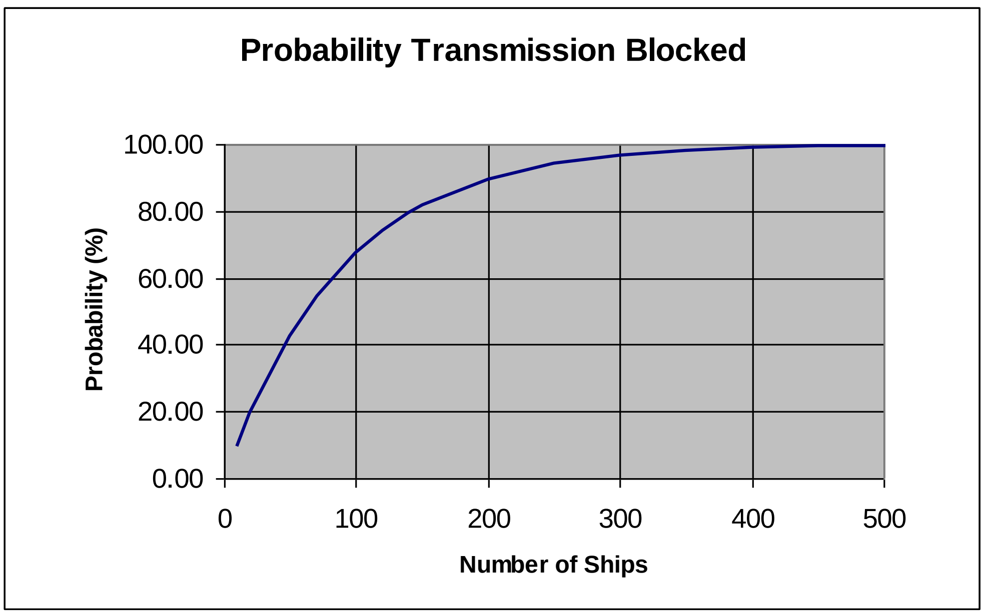


Figure 1. USCG Parameters.

The probability of a collision is much higher than predicted by the contractor; for example with 400 ships the contractor finds that the probability is about 92 percent. However, if the constant of 1.7 is reduced to 1, the curve in Figure 2 is obtained; this appears to be identical to the corresponding curve in the contractor's report. When the analysis is repeated for the other transmission repeat rates used by the contractor, the other the contractor curves are obtained. These too appear identical to the contractor's probabilities. This strongly suggests that the contractor has not defined a collision properly by neglecting the factor 2 (alternatively 1.7 or perhaps some other value) in the numerator of equation (2).

The contractor presents a further set of curves that depict the probability, Q, of a ship that is missed as a function of time. A miss is defined as a failure to obtain at least a fixed number of clean messages, such as 3 or 5 messages. The probability of receiving no clean messages is given by:

$$Q(0) = (1 - p^{N-1})^{M} \tag{3}$$

where M=t/T and t is the time. When the threshold is three clean messages, the probabilities of not receiving exactly one and exactly two messages must be added to this probability.

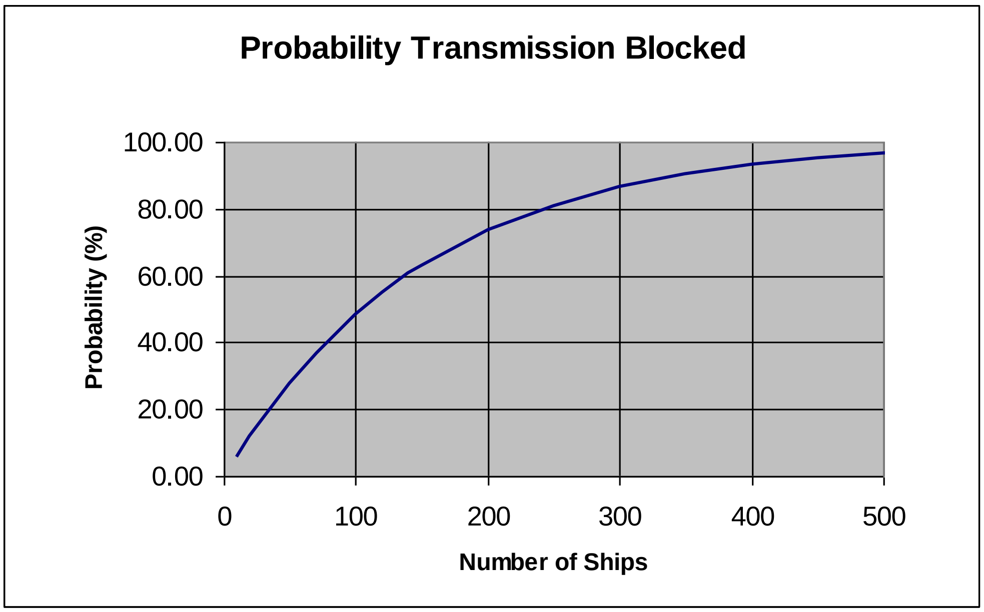


Figure 2. The contractor's parameters with missing factor.

The remaining probabilities are given by the binomial distribution with a probability of success P and failure Q at each independent trial:

$$Q(j) = \binom{M}{j} P^{j} Q^{M-j} \tag{4}$$

where in this case j=0,1,2 and

$$Q = 1 - p^{N-1}$$
$$P = p^{N-1} \tag{5}$$

The sum of these is calculated for a population of 500 ships and a repeat time of 10 s and the result is shown in Figure 3. A factor of 1.7 is used in the numerator of equation (2) as advocated by the USCG. Relative to the contractor's curves, Figure 3 indicates a worse performance. Again the calculation was run with a factor of 1 rather than 1.7: the result is shown in Figure 4. This is much closer to the contractor's result. Nevertheless, there are significant differences in as much as the contractor's simulations suggest far fewer collisions at large times. Again this suggests that the contractor did not define a collision properly and that the results of their simulation are in any case too optimistic.

Finally the probability of receiving a single clean signal is calculated from equation (1) as a function of the number of ships. This is shown in Figure 5 for a transmission time interval of 6 s and a total reception time of 600 s so that the result can be compared with that of the USCG. The results appear to be identical.

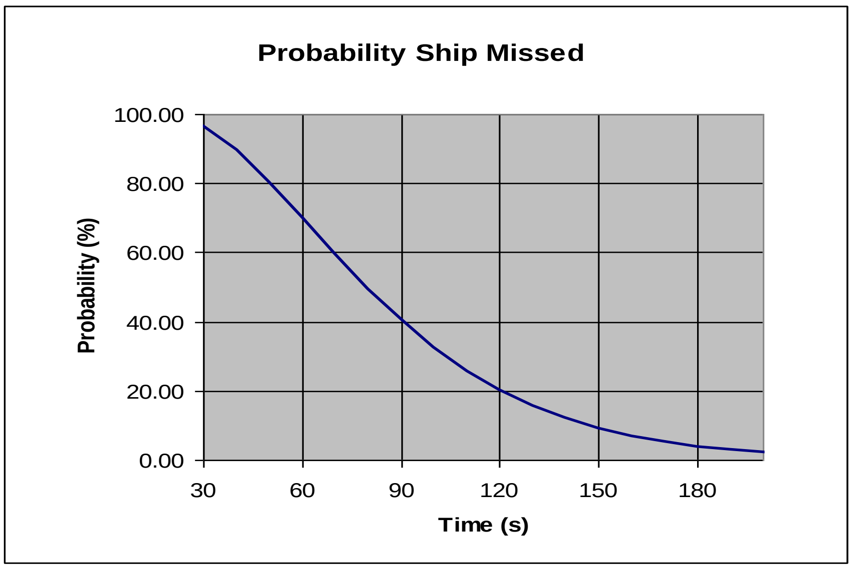


Figure 3. Number of ships=500; USCG Factor 1.7.

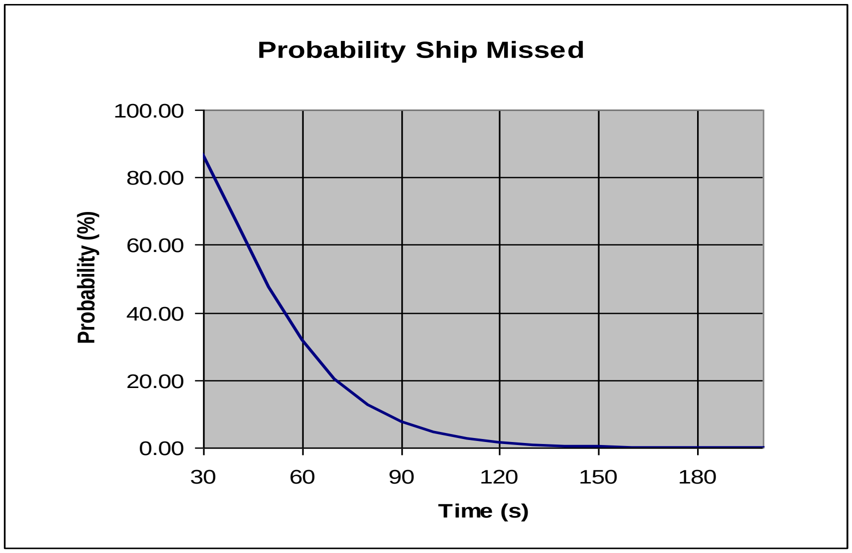


Figure 4. The contractor's parameters; 500 ships.

This analysis allows a study of the effects of changes to the receiver antenna beam on the performance. If the beam width is reduced in azimuth, there are two effects. Firstly the number of ships in the beam is reduced and secondly the time that a ship is in the beam is reduced. The question arises as to whether it is advantageous to use a wide beam or a narrow beam.

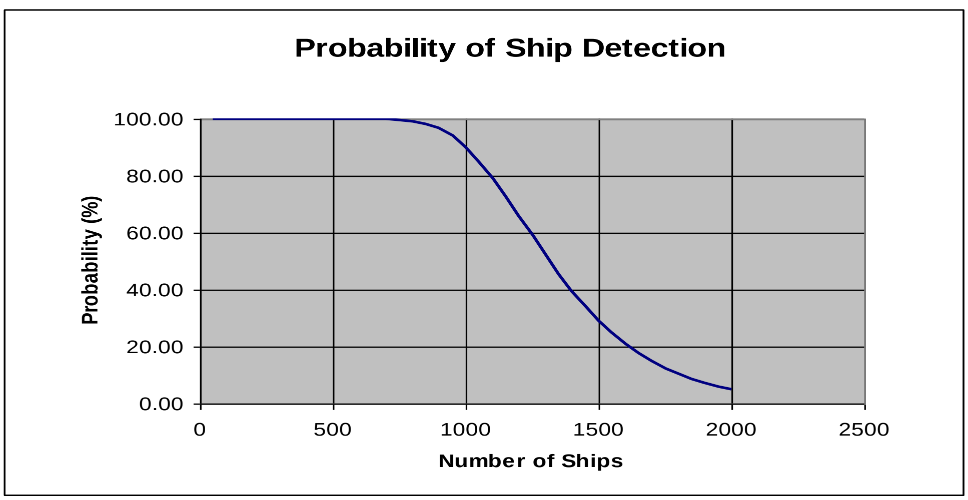


Figure 5.

The effect of reducing the beam area in azimuth by a factor of 2 while simultaneously reducing the number of ships in the beam by a factor of two is shown in Figure 6. For direct comparison, the x-axis is not changed so that it now represents a ship area density, which is the same as in Figure 5.

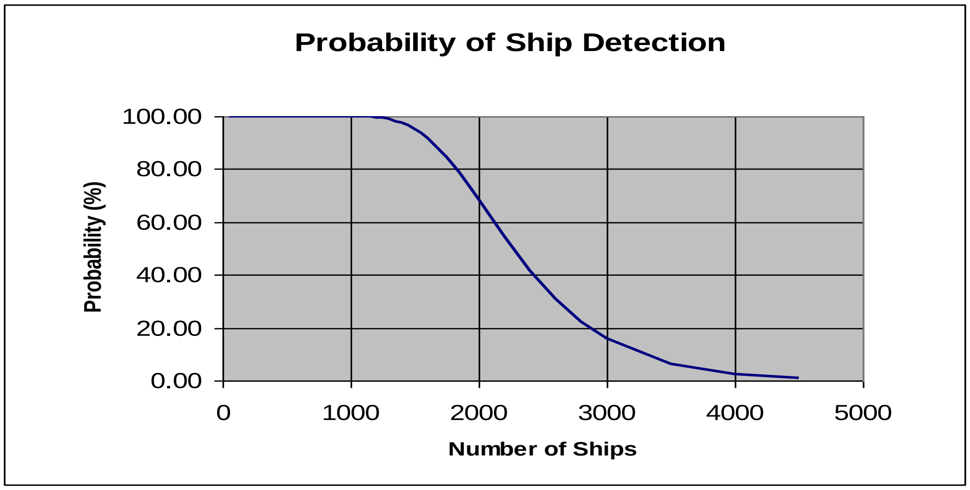


Figure 6.

As can be seen, there is a great improvement in performance. For example, at the 90 percent level, the number of ships that can be detected from the wide beam is about 1000. From Figure 6, when the beam is narrowed by a factor of 2, the number of ships that can be detected in a single beam at the 90 percent level is half of about 1600. If these ships are spread out evenly in azimuth, the total number that can be detected during the 600 s fly-by time is doubled to 1600; this is a 60 percent improvement.

The contractor's conclusions are reasonable except the performance is likely to be somewhat worse than they predict. The effect of background noise due to AIS Class B transmitters has not been studied and this will probably require a narrow beam. Clearly more study is needed, especially on the effects of beam width and on the reconciliation of the collision models.

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