RTCA Special Committee 186, Working Group 3

ADS-B 1090 MOPS, Revision A

Meeting #16

Air--to-Air Reception in LA2020 and the Low Density Environment

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SUMMARY

Lincoln Laboratory has been using two simulation tools to determine ADS-B reception performance as a function of range for the LA2020 high density environment. Performance results were presented at the previous WG-3 meeting. As discussed at the meeting, it was decided to make additional runs including the effects of receiver blanking for co-site interference, and using a different model to represent the benefit of having top-bottom antenna diversity on reception. The results from these additional runs are presented in this working paper. In addition, performance in the standard low-density environment was also evaluated. The performance results are documented in this working paper.

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This study makes use of two simulations that were developed previously. The first tool is a pulse-level simulation, whose output gives the probability of correct reception of an Extended Squitter signal as a function of received signal power level. The second tool is a track-level simulation, whose input is the per-squitter reception probability from the pulse-level simulation, and whose output gives the performance over a time period such as 12 seconds. When applied to long-range air-to-air surveillance, this simulation can be used to determine the maximum range at which 95 percent or more of the targets are being received sufficiently reliably to be in track and being updated regularly as required by the ADS-B MASPS (RTCA DO-242A).

1. Pulse-Level Simulation

The pulse-level simulation generates a sample-by-sample received Extended Squitter signal in the presence of interference, consisting of Mode A,C fruit and Mode S replies and squitters, in both long and short formats. When used in this study, the interfering reception rates and power distributions were selected to match the interference environment in Los Angeles in one case and the low density environment in the other. The formulation of this simulation and the simulation results are documented in my paper from the previous meeting (WP-15-13), so it is not necessary to repeat that material here. This portion of the performance evaluation has not changed.

2. Track-Level Simulation

After the pulse-level simulation has generated results in the form of reception probability as a function of received signal power, the track-level simulation can be used to determine system performance.

2.1 **Formulation**

The track-level simulation is formulated using a Monte Carlo technique in which one run represents one pair of aircraft at a given air-to-air range. In each run, pseudo random variables are used to generate the antenna gain values and the transmitter power for that particular transmitting aircraft.

The TLAT model is used for the statistical variation of aircraft antenna gains. The scenario considered in these runs applies to altitudes that are nearly the same, and for which the antenna vertical patterns are not used. Altitude differences were studied separately, as described below.

After being generated at random, the antenna gain values are held constant for that particular pair of aircraft. The cases being addressed in this study apply to antenna diversity on both the transmitting and the receiving aircraft. Therefore each aircraft pair has four antenna gain values. These four values are generated independently in the simulation. Transmitter power, for a class A3 aircraft, is modeled as uniformly distributed over 53 to 56 dBm referred to the antenna.

The simulation is run for a particular air-to-air range. Using the transmitter power and the four antenna gains, the four values of received power are calculated (top-to-top, top-to-bottom, bottom-to-top, and bottom-to-bottom). For each case the probability curve (from the pulse-level simulation) is then used to determine the reception probability for that particular antenna combination.

Receiver blanking caused by co-site interference is included at this point. The values of reception probability calculated as above are now multiplied by 0.93 to account for these effects.

To account for receiving antenna diversity, the probability of correct reception is calculated using the following formula.

$$\text{Prob(correct)} = \text{Maximum}[P(\text{top}) , P(\text{bot})]$$

where P(top) and P(bot) are the reception probabilities for top only and bottom only. In other words, only the better of the two receiving antennas is used; the other does not contribute to performance.

Subsequently, to account for transmitting antenna diversity, the reception probability is calculated separately for top-transmit and bottom-transmit, and then these two values are averaged. This averaging is based on the fact that each antenna transmits 50 percent of the squitters.

This process yields the value of reception probability for a particular pair of aircraft. The process is repeated for a large number of aircraft pairs (1000 pairs). Performance for the 95th percentile pair is determined by sorting the 1000 values and identifying the value that is exceeded by 95 percent of the population. This result gives the 95-percentile reception probability for the range being considered. Repeating the process for different ranges provides system performance as a function of range.

2.2 **Simulation Results**

For the LA2020 scenario (24,000 ATCRBS/sec.), both the pulse-level simulation and the track-level simulation were run, yielding the results given in Table 1 and the two figures that follow. Results in the probability form (Figure 1) are somewhat general, in the sense that the needed level of reception probability depends on specifics of different cases. For example, for air-to-air surveillance, a value of 0.061 is sufficient to provide MASPS-compliant performance at long range (20 nmi and beyond) [Ref. 3].

Table 1. Performance as a Function of Range.

RANGE nmi	Prob(95) Recep. Prob.	T95/95 sec.
10	0.681	0.7
20	0.429	1.3
30	0.272	2.4
40	0.185	3.7
50	0.130	5.4
60	0.106	6.7
70	0.077	9.3
80	0.058	12.5
90	0.055	13.2
100	0.045	16.3

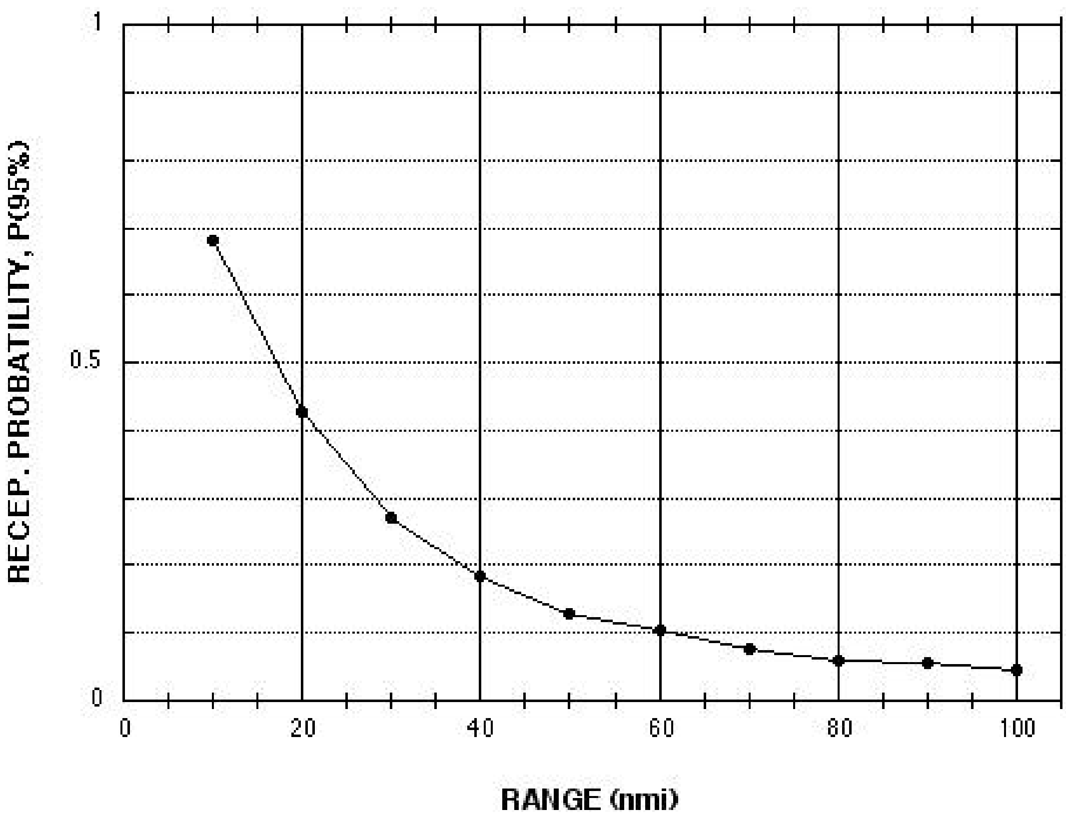

Figure 1. Reception Probability (95 percentile worst case) vs. Range (LA2020).

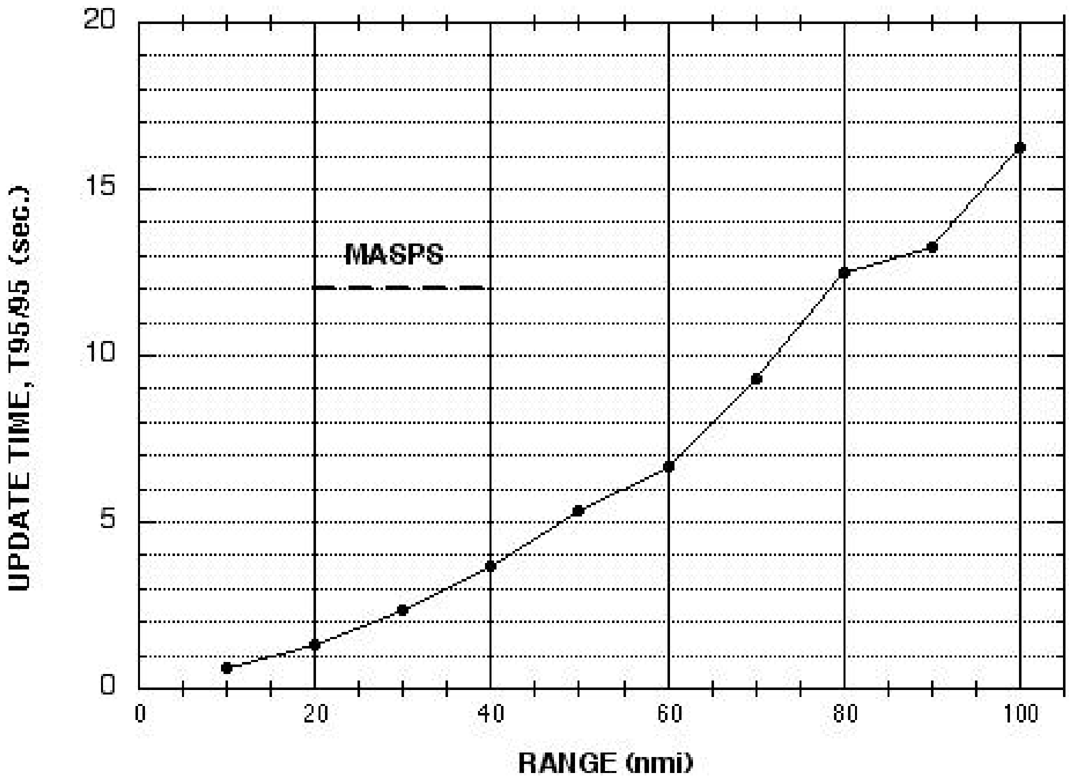

Figure 2. Surveillance Performance as a Function of Range (LA2020).

The results in Figure 2, showing surveillance update time were generated from the probability values as follows. In a time T, the number of reception opportunities is

$$N = T / 0.25 \text{ seconds.}$$

Given the reception probability from the pulse-level simulation, the probability of correct reception during the time T is therefore

$$P(\text{recep. in } T) = 1 - (1 - p1)^N$$

where p1 is the single-squitter reception probability. Requiring 95% reception in time T, or P(recep. in T) = 0.95, the solution for time T is:

$$T95 = 0.25 * \ln(0.05) / \ln(1 - p1)$$

This calculation is made for each pair of aircraft among 1000 pairs. The results are sorted, in order to determine the T95 value for which performance is as good or better for 95 percent of the aircraft pairs. The result is denoted T95/95 to indicate that it applies to 95% surveillance update reliability for 95% of aircraft pairs.

3. Effects of Altitude

As reported in the previous WG-3 meeting, we added altitude to the simulation in order to determine the effects of an altitude difference between the transmitter and the receiver. In the normal formulation, the two aircraft are considered to be at approximately the same altitude, and therefore the elevation-angle portion of the antenna gain model was not used (only the statistical portion was used). For this additional study, the formulation was changed so that the transmitting aircraft has a specific altitude (a parameter entered by the user) and the receiving aircraft has a specific altitude (another parameter entered by the user). We assigned the receiving altitude to be 40,000 feet, and assigned the transmitting altitude one of several values. Therefore the results depend on the transmitter altitude. The TLAT model of aircraft antenna gain as a function of elevation angle was used in this study [Ref. 4].

Results of this kind are given in the previous working paper (WP-15-13). These results indicate that performance is degraded when the transmitter is changed from 40,000 feet to 5000 feet, with the degradation occurring inside of 50 nmi. Beyond 50 nmi, performance is essentially unchanged.

Looking at the intermediate results from the simulation, I can see several reasons why altitude would not have much effect at long range. For long range, the elevation angle change is small. For example, for range of 100 nmi and transmitter altitude of 5000 feet, the elevation angles are +/-3.3 degrees. According to the TLAT antenna gain model, this causes a drop by only 1.1 dB for one antenna and a boost by 1.0 dB for the other. The effects are small and nearly identical.

4. Low-Density Environment

A specific "Low Density Environment" is defined in the TLAT report [Ref. 4, Appendix H]. The aircraft are uniformly distributed in area over a circle of 400 nmi radius. The total number of aircraft is 360, so the density is 0.0007 aircraft per square nmi.

4.1 Reception Probability vs. Signal Power

In evaluating performance in this environment, the first step was to determine reception probability as a function of range. This can be done using the pulse-level simulation, but that was not done here because of the limited scope of this effort. Instead a comparison was made between the LA2020 fruit rate and distribution and the corresponding rate and distribution of the low density environment. The following values compare the number of aircraft for several values of range.

For R = 400	LA2020 = 2469 a/c	LowDen = 360 a/c	ratio = 5:1
For R = 200	LA2020 = 1071 a/c	LowDen = 90 a/c	ratio = 12:1
For R = 100	LA2020 = 532 a/c	LowDen = 23 a/c	ratio = 23:1
For R = 50	LA2020 = 257 a/c	LowDen = 6 a/c	ratio = 43

Because the distribution of aircraft in range is so different in these two models, the shape of the fruit distribution curves are quite different. The following values relate range to fruit power levels.

For R = 400	ratio = 5:1	power = -96 dBm
For R = 200	ratio = 12:1	power = -90 dBm
For R = 100	ratio = 23:1	power = -84 dBm
For R = 50	ratio = 43	power = -78 dBm

These values make it possible to estimate the fruit rate and distribution for the low density environment, if the interrogation environment were the same. Comparing these two curves, we noted the amount of power difference for a given fruit rate -- which is the horizontal separation between the two curves when plotted as fruit rate (vertically) vs. power (horizontally). Knowing this, we can estimate reception probability by shifting the LA2020 probability to the left by that amount. The separation is seen to be more than 20 dB, which indicates that the effects of fruit would only be significant for signals far below MTL. In other words, for signals above MTL, fruit does not have a significant effect on reception probability. This conclusion applies for reception probabilities lower than 0.50. For higher values of reception probability, fruit may have some effect, but this portion of the curve will not affect long range system performance.

The conclusion is that the MTL curve by itself is an appropriate characterization of reception performance as a function of received power in the low density environment. Therefore we used that curve as the input to the track-level simulation. The particular curve we used was obtained from benchtest measurements at the Tech Center. Tom Pagano provided benchtest curves on 4 December to APL and Lincoln, which included two curves under MTL conditions. One of these curves satisfies both MTL requirements (the 90% requirement and the 15% requirement). This is the curve we used as input to the track level simulation.

4.2 Track-Level Simulation

The track-level simulation was now run, using the same procedure as for LA2020 except for the probability input curve, which embodies the characteristics of the low density environment. The runs apply to class A3 transmissions received by class A3 aircraft. Both aircraft have antenna diversity. A receiver deadtime factor of 0.93 was also used.

The simulation results are given in the following table and two figures. Seeing some statistical fluctuations in the simulation results, we ran the simulation two times at each range. Both points are tabulated and plotted, which serves as an indication of the degree of accuracy in these results as influenced by the number of trials (1000 aircraft pairs contributing to each point).

Table 3. Performance in the Low Density Environment.

RANGE nmi	REC. PROB. P(95)	T95/95 sec.
70	0.696	0.629
70	0.676	0.665
80	0.481	1.142
80	0.552	0.933
90	0.465	1.197
90	0.465	1.197
100	0.465	1.197
100	0.465	1.197
110	0.464	1.201
110	0.402	1.457
120	0.215	3.094
120	0.278	2.299
130	0.142	4.890
130	0.094	7.587
140	0.018	41.232
140	0.018	41.232

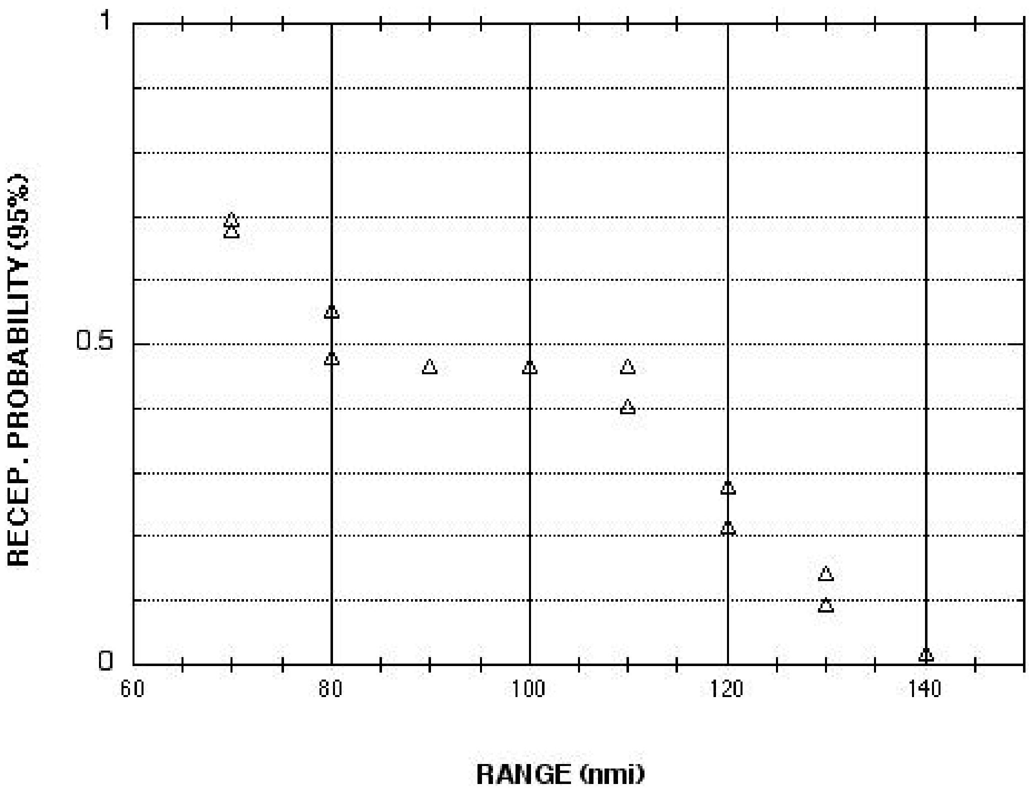

Figure 3. Reception Probability in the Low Density Environment.

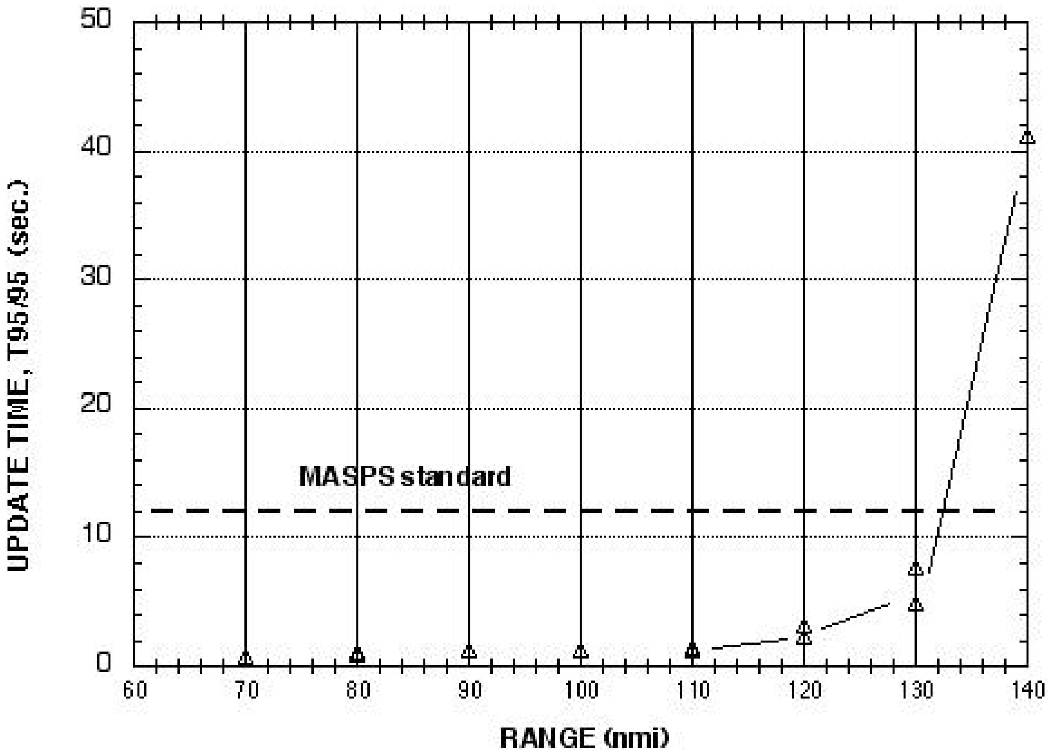

Figure 4. Surveillance Updates in the Low Density Environment.

The results exhibit an interesting flat spot from 80 to 110 nmi. Looking at this, we can see that it is a result of the steep MTL curve. It's not common, but occurs at around the 95 percentile worst cases, that one of the two transmitting antennas has higher power, for which reception is the maximum value (0.93), while the other transmitting antenna has lower power, for which reception is zero. Therefore the overall probability is (0.93 + 0)/2 = 0.465. This is the probability value at the flat spot.

In summary, performance extends to about 131 nmi in the low density environment, for class A3 to A3 surveillance.

REFERENCES

1. "Measurement of 1090 MHz Extended Squitter Performance In the Los Angeles Basin," DOT/FAA/ND-00/7, May 2000.

2. A. G. Cameron, et al, "The 1030/1090 MHz Interference Simulation Technical Description and Initial Results," TR-9454-02-01, TASC Inc., April 2001.

3. "1090 MHz Extended Squitter Assessment Report," prepared by the FAA and EUROCONTROL, June 2002, Appendix B.

4. "Technical Link Assessment Report," Safe Flight 21 Steering Committee, ADS-B Technical Link Assessment Team (TLAT), March 2001.