RTCA Special Committee 186, Working Group 5

ADS-B UAT MOPS

Meeting #5

Action Item 3-22
Latency in ADS-B

Presented by

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SUMMARY
Latency in ADS-B data is of interest from two points of view: (1) the lag, or delay, in delivery of accurate surveillance information associated with a dynamic threat scenario to the supported threat detection application, and (2) time registration errors associated with combining ADS-B and other surveillance data sampled at different times. Both considerations are generally less demanding in air-air self-separation applications than in third party, i.e., ATC, applications since own-ship delays are typically lower than those associated with delivery of two-party data to a third user.

1.0 Overview

Latency in ADS-B data is of interest from two points of view:

- the lag, or delay, in delivery of accurate surveillance information associated with a dynamic threat scenario to the supported threat detection application,
- time registration errors associated with combining ADS-B and other surveillance data sampled at different times.

Both considerations are generally less demanding in air-air self-separation applications than in third party, i.e., ATC, applications since own-ship navigation output delays are typically lower than those associated with delivery of two-party data to a third user.

Delay in delivery of relative position data to a conflict detection application means the relative separation of two aircraft in a closing encounter is smaller than that estimated on the basis of the aged data. Delay in heading data for a turning aircraft means the track extrapolation based on this estimate will lag the current track. These delays basically reduce the conflict alert time potentially available if data were instantly available to the application.

Sampling time differences when combining surveillance data on a single aircraft from different sources means the combined estimate for the moving target must account for the aircraft motion during the sampling interval. Compensation for a non-maneuvering aircraft requires an estimate of the current velocity. Compensation for a maneuvering aircraft requires an estimate of the current acceleration. If these uncompensated relative delays are large enough, the tracker may report multiple targets rather than the actual single aircraft. These uncompensated time registration errors basically limit target resolution in the sensor integration process.

2.0 Surveillance Lag Time Effects

ATC radar outputs have some delay since they process target data as they scan. Further delays are incurred in communicating this data to the air traffic controller. NAS Specifications for sensor processing delays are 0.8 seconds for terminal area radars, and 1.5 seconds for enroute radars. Communication and automation delays increase total lag times to 2.2 seconds and 3.5 seconds respectively. Total delay for parallel approach monitoring radar is one second, and presumably, communication delay is a small part of this total.

Directly applying these specifications to ADS-B means the ATC receiver output state vector report latency should not exceed 0.8 seconds. The along track position error, Ea, is given by Ea = v*tb/3600 NM for an aircraft moving at v knots and a position report delay of tb seconds. An aircraft moving at 300 kts with a report delay of 0.8 seconds has an along track displacement error of 0.067 NM. Twice this error (for reduction in relative separation of two aircraft closing at these speeds) is only 0.13 NM which is about 4 percent of the 3 NM separation minimum. Doubling this latency produced separation reduction for 600 kt speeds in enroute airspace gives a 5 percent bias error in the 5 NM enroute minimum separation standard. The more operationally significant error, the 0.8 sec delay produced track extrapolation lag error of 2.4 degrees for a three degree/sec turn, is probably still much better than the comparable radar based estimate.

To meet this 0.8 sec latency on high performance aircraft, UAT may need to extrapolate the position part of the GNSS state vector output at the UTC second mark to the midpoint of the broadcast time of 0.6 seconds. This track extrapolation should not be required, however, for A0 or A1 equipage class users if these aircraft meet the same maximum speed of 175 kts (and maximum altitude of 15,000 feet) low category restrictions employed in Mode-S specifications. Some relaxation in this overall source-to-application latency should also be possible in supporting air-to-air applications since, in this case, the receiving aircraft has complete knowledge of its state and near term intent.

3.0 Time Registration Effects

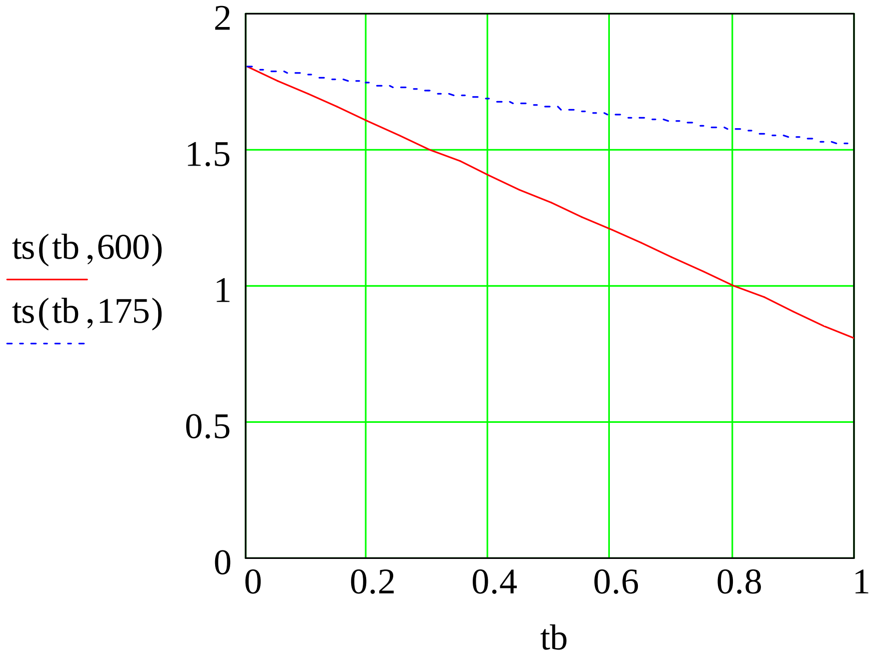
Relative delays between ADS-B reported position and that estimated by another sensor are of direct interest in implementing the UAT capability to provide independent range confirmation of the ADS-B position derived from GNSS. In this case, own-ship position is combined with the received ADS-B position of the reporting aircraft to calculate the separation slant range at the time of the report. This range is then compared with that determined from the 6 usec/NM propagation delay from the time synchronized broadcast source. Using the altitude differences of the receiving and reporting aircraft, the measured propagation delay defines a circle on this constant altitude plane centered on the receiving aircraft. Since any potential broadcast source lies on this circle, the reported GNSS position is verified if it lies within some acceptable deviation limit about this circle. This is also an effective anti-spoofing capability since a nefarious source broadcasting virtual ADS-B positions would be highly unlikely to meet the independent range test.

Passive range verification of ADS-B computed range depends on a determination of whether the two range estimates differ by no more than some operationally tolerable amount. The desire that the test does not reject valid data or accept erroneous data determines this amount. A worst case difference in these range estimates is illustrated by considering an aircraft approaching at a speed, v kts, with an average non-extrapolated position report broadcast latency of tb seconds, and an uncompensated time synchronization delay of ts usec. In this case, the difference in range estimates, δ NM, is the sum of the closing range error associated with delayed broadcast, v*tb/3600, and uncompensated time synchronization error, ts/6. From this, the maximum acceptable value of ts can be expressed as

$$ts(tb, v) := 6 \cdot \left(\delta - \frac{v \cdot tb}{3600} \right)$$

With a minimum separation standard of 3 NM, a 95 % confidence that the difference in estimates, δ, is no greater than 0.3 NM seems reasonable. Figure 1 shows acceptable average values of ts usec as a function of tb sec for this assumed 0.3 NM difference.

$\delta = 0.3$



Uncompensated synchronization delay (ts usec) vs non-extrapolated track delay (tb sec) for δ = 0.3 nmi and closing aircraft speeds of 600 kts and 175 kts

Figure 1

This shows, for example, that a combination of tb = 0.6 sec and ts = 1.2 usec should meet the 0.3 NM difference for an approaching speed of 600 kt.

To assure that variances in reported positions (the basis for calculated slant range) and compensated time synchronization (the basis for passive range measurement) do not cause valid tracks to be rejected, we employ a means comparison test. Assume experience shows the GNSS derived separation range has a mean, Rg, and standard deviation, σg. Using the standard statistical means test for normally distributed parameters [Ref 1], we can say the bounds on the passive range mean, Rp, and standard deviation, σp, estimated from a set of n difference measurements is given by

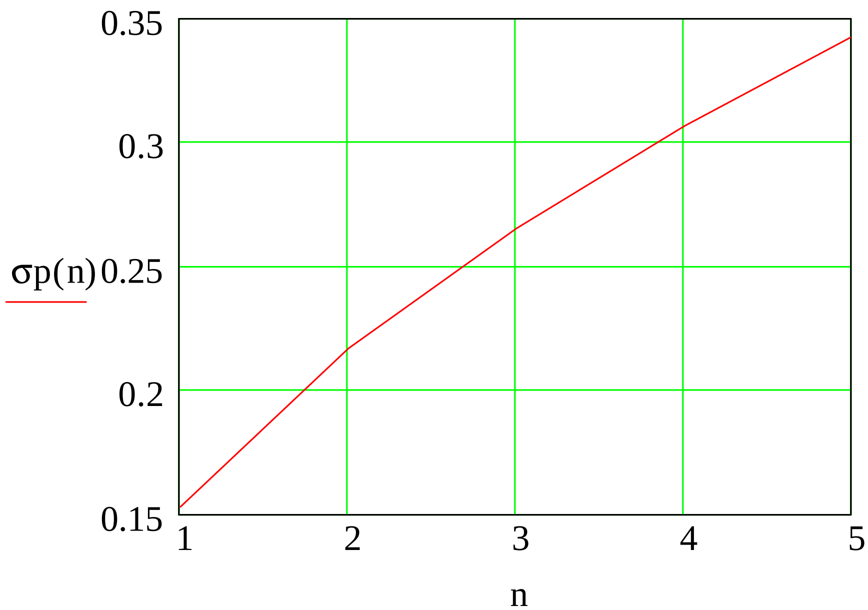
$$|Rg - Rp| \leq 1.96 \cdot \sqrt{\frac{\sigma g^2}{n} + \frac{\sigma p^2}{n}}$$

Solving for σp with δ = |Rg – Rp|,

$$\sigma p(n) := \sqrt{n \cdot \left(\frac{\delta}{1.96} \right)^2 - \sigma g^2}$$

Maximum acceptable values of passive ranging standard deviation as a function of number of comparison measurements for verification are plotted in Figure 2 for a 0.3 NM maximum difference in means (assumed to be operationally acceptable), and a GNSS standard deviation of 15 meters or 0.0081 NM.

$\sigma g = 0.0081$ $\sigma g = 0.0081$



Acceptable value of passive range std dev, σp, vs number of verification measurements made for a difference in means, δ, and 95% confidence level

Figure 2

Based on this curve, passive range time variations (1σ) from 0.9 usec (0.15 NM) for n = 1 to 2 usec (0.34 NM) for n = 5 are acceptable if the 95% limits on range differences is 0.3 NM and the GNSS standard deviation is 15 meters.

4.0 Summary

ADS-B state vector report delays of 0.8 sec should meet NAS surveillance latency requirements, but passive range verification constraints limit this to about 0.6 sec for high speed aircraft if the average uncompensated time synchronization delay is 1.2 usec. Depending upon the number of passive range/GNSS range measurements processed, a 1σ variation in passive range timing of one to two microseconds should assure independent confirmation within 0.3 NM if one to five range difference measurements are averaged for verification.

Reference 1: Experimental Statistics, NBS Handbook 91, U.S. Government Printing Office, 1963