[EN-A-060] ADS-B latency estimation technology for surveillance performance assessment

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Abstract: ADS-B is one of the promising technologies for aircraft surveillance. ADS-B provides air traffic users with high accurate GNSS positions with high update rate. This feature will improve the safety and efficiency of air traffic. However, ADS-B user can not benefit with the accuracy capability since the ADS-B message does not include GNSS measured time and the latency between the GNSS measured time and ADS-B message arrival time. In this paper, we propose a technology to estimate ADS-B latency. Then, we apply the proposed technology to real data obtained by ENRI experimental system and show results of the estimations.

Keywords: ADS-B, latency

1. INTRODUCTION

Automatic Dependent Surveillance-Broadcast (ADS-B) is one of the promising technologies for aircraft surveillance. Aircraft positions with high update rate and GNSS accuracy will improve safety and efficiency of air traffic. In ADS-B, Aircraft can broadcast its positon of meter-order accuracy by GNSS positioning. However, ADS-B user can not benefit with the accurate capability since the ADS-B position report does not contain GNSS measured time. An ADS-B ground station is able to obtain only ADS-B report arrival time measured by own clock.

The total latency of position information is the delay between the time of applicability of the position measurement and the time of arrival of the ADS-B message for that position. It is one of the important factors for the performance of ADS-B systems, because the total latency has directly influence on its positions. Large latency become a cause of serious position error.

In the ref. [1] and [2], the total latency has been estimated by summing up the values regulated in international standards or regulations of ADS-B systems. However, it is difficult to measure and evaluate the actual value of the total latency.

In this paper, we propose a technology to estimate the standard deviation of the ADS-B total latency. Then, we apply the proposed technology to real data obtained by ENRI experimental system and show results of the estimations that indicate the effectiveness of the proposed technology.

The structure of this paper is as follow. In section 2, we discuss the latency of ADS-B. In section 3, we propose a technology to estimate the standard deviation of the total latency. In section 4, we apply the proposed technology to real ADS-B data observed in ENRI experimental system. In Section 5, we conclude this paper.

Extended squitter ADS-B has two different timing modes, one is coupled to GNSS timing and another is uncoupled. In this paper, we only discuss uncoupled mode because most of aircraft are using uncoupled mode.

2. ADS-B LATENCY

The latency of ADS-B is discussed in [1] and [2]. The functional architecture of a transmitting aircraft and a ground ADS-B receiver is shown in Fig. 1. This figure is based on slide 12 of [2]. This is also mixture of the RTCA functional architecture diagram (Figure U-1 in [1]) and the general timing diagram (Figure U-2 in [1]).

In Fig. 1, each block shows components of ADS-B systems. The capital letters at the top show the interfaces between components. For example, A1 indicates Input to the Measuring equipment. The considerations in [2] and [3] don't include the delay at the ground systems. We add two blocks (ADS-B receiver and computer) to the functional architecture and define their interfaces as R1, R2 and R3. Even if the latencies in the ground systems are negligible, it is important to understand the relation between onboard measured time and ground measured time.

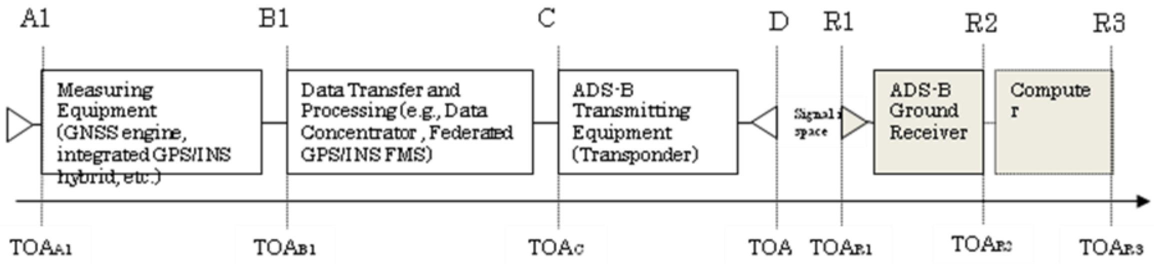

Figure 1. Functional architecture diagram with general timing

TOAx is the true time of applicability of the data that crosses interface X. The detailed relations between time and delay in sub systems and in total system is discussed in [1], [2] and [3].

The total latency (*TL*) of position information is the delay between the time of applicability of the position measurement and the time of arrival of the decoded report on that position.

TL is shown as follow,

$$TL = TOA_{R3} - TOA_{A1}. \qquad (1)$$

3. LATENCY ESTIMATION TECHNOLOGY

In this section, we propose a ADS-B latency estimation technology. This technology can estimate the standard deviation of the total latency. We focus on the dynamic part of total latency which lead noisy position errors.

3.1 Requirements

The requirements for applying this technology are

- The onboard GNSS receiver measures accurate positions and time.
- The velocities (ground speed) of aircraft are computed from the positions and time.
- The clock at a ground receiver keeps accurate time.

The ADS-B systems does not satisfy these requirements. It is not possible to estimate the deviation of the total latency.

3.2 Consideration on the total latency

To simply the discussion, we define two types of the latency, the constant latency (*CoL*) and the inconstant latency (*InL*) in ADS-B system.

CoL is constant and specific to each ADS-B equipment. It is fixed values and does not change by each event. In contrast, *InL* is variable and changes on every events.

The relation among *TL, CoL and InL* is shown as follow,

$$TL = CoL + InL. \qquad (2)$$

3.3 Computation

We consider that a ADS-B onboard system transmits the ADS-B position reports at the event 1 and 2. An ADS-B ground equipment receives the reports containing GNSS positions at each time of TOA_{A1}. These reception times for the event 1 and 2 are shown as follows,

$$TOA_{R3\_1} = TOA_{A1\_1} + CoL + InL_1, \qquad (3)$$

$$TOA_{R3\_2} = TOA_{A1\_2} + CoL + InL_2. \qquad (4)$$

The ground speed *(v_{mes})* that the ground receiver computes from ADS-B position reports and ground clock measured time is shown as follow,

$$v_{mes\_12} = \frac{R_{12}}{TOA_{R3\_2} - TOA_{R3\_1}}, \qquad (5)$$

where *R12* is the distance between ADS-B positions at the event 1 and 2.

The ground speed *(v_{true})* that the GNSS receiver computes from GNSS position and GNSS clock measured time is shown as follow,

$$v_{true\_12} = \frac{R_{12}}{TOA_{A1\_2} - TOA_{A1\_1}}. \qquad (6)$$

The time difference of TOA_{R3_1} and TOA_{R3_2} is shown as follow,

$$TOA_{R3\_2} - TOA_{R3\_1} = \frac{R_{12}}{v_{mes\_12}}. \qquad (7)$$

By the equation (3) and (4), the equation (7) is modified as follow,

$$(TOA_{A1\_2} + CoL + InL_2) - (TOA_{A1\_1} + CoL + InL_1) = \frac{R_{12}}{v_{mes\_12}}. \qquad (8)$$

Then, the constant latency is cancelled and the difference of the inconstant latency remains in the equation.

$$(TOA_{A1\_2} - TOA_{A1\_1}) + (InL_2 - InL_1) = \frac{R_{12}}{v_{mes\_12}}. \qquad (9)$$

By the equation (6), the equation (9) is modified as follow,

$$\frac{R_{12}}{v_{true\_12}} + (InL_2 - InL_1) = \frac{R_{12}}{v_{mes\_12}}. \qquad (10)$$

The difference of the inconstant latencies (ΔInL_{12}) is shown as

$$\Delta InL_{12} = InL_2 - InL_1 = \frac{R_{12}}{v_{mes\_12}} - \frac{R_{12}}{v_{true\_12}}. \quad (11)$$

In the same way, the difference of the inconstant latencies at the event *i* and *i+1* is shown as follow,

$$\Delta InL_{i,i+1} = (InL_{i+1} - InL_i) = \frac{R_{i,i+1}}{v_{mes\_i,i+1}} - \frac{R_{i,i+1}}{v_{true\_i,i+1}}. \quad (12)$$

The mean of inconstant latency (*InL*) is zero, because *InL* is randomly changing value from the definition, and the *InL* at each event has no correlation. By these conditions, the mean and standard deviation of $\Delta InL_{i,i+1}$ is computed as follows,

$$Mean = \frac{1}{n}\sum_{i=1}^{n} \Delta InL_{i,i+1} = \frac{1}{n}\sum_{i=1}^{n} (InL_{i+1} - InL_i) = 0. \quad (13)$$

$$\begin{aligned} Std &= \sqrt{\frac{1}{n}\sum_{i=1}^{n}\{\Delta InL_{i,i+1} - Mean\}^2} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\{\Delta InL_{i,i+1}\}^2} \\ &= \sqrt{\frac{1}{n}\sum_{i=1}^{n}\{InL_{i+1} - InL_i\}^2} \\ &= \sqrt{\frac{1}{n}\sum_{i=1}^{n}\{InL_{i+1}^2 - 2\cdot InL_{i+1}\cdot InL_i + InL_i^2\}} \\ &= \sqrt{\frac{1}{n}\sum_{i=1}^{n} InL_{i+1}^2 - \frac{1}{n}\sum_{i=1}^{n}\{2\cdot InL_{i+1}\cdot InL_i\} + \frac{1}{n}\sum_{i=1}^{n} InL_i^2} \\ &\approx \sqrt{\frac{1}{n}\sum_{i=1}^{n} InL_{i+1}^2 + \frac{1}{n}\sum_{i=1}^{n} InL_i^2} \approx \sqrt{\frac{2}{n}\sum_{i=1}^{n} InL_{i+1}^2}. \end{aligned} \quad (14)$$

This equation means that the standard deviation of the inconstant latency (*InL*) is $1/\sqrt{2}$ of the standard deviation of $\Delta InL_{i,i+1}$ that we can obtain from observations.

4. RESULTS OF EXPERIMENTS

4.1 Experimental ADS-B ground system

In experiments, we use the OCTPASS system which is developed as airport surface multilateration. By bench tests, we confirmed that the system has the highly accurate time stamp capability. The time stamp error is less than 1ms seconds. This is sufficiently small compared to hundred milliseconds latency at airborne systems.

4.2 Ground speeds

Three types of ground speed (GS) is available from obtained data.

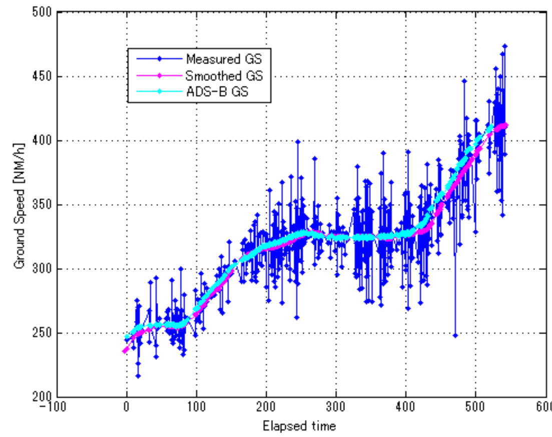

Figure 2. The GS of an aircraft

The first GS is "ADS-B GS" which contained in ADS-B velocity report. This ADS-B GS is corresponding to v_{true} in equation (6).

The second GS is "measured GS" that computed from positions in consecutive ADS-B position reports and time at which the ground equipment receives the ADS-B position reports. This measured GS is corresponding to v_{mes} in equation (5).

The third GS is "smoothed GS" that computed from positions in ADS-B position reports that separated for certain amount of time (ex. 20 seconds) and the time that the ground equipment receives the corresponding ADS-B position reports.

Figure 2 shows that three ground speed of an aircraft trajectory. The blue, magenta and cyan lines indicate the measured GS, the ADS-B GS and the smoothed GS respectively.

The smoothed GS and ADS-B GS vary smoothly and both values are matching very well. On the other hand, measured GS is noisy and contains errors.

4.3 Estimated latency

Then, we compute the difference of the inconstant latency ($\Delta InL_{i,i+1}$) from ADS-B position report and time stamp on the ground.

Figure 3 shows computed $\Delta InL_{i,i+1}$ from one aircraft trajectory. In this aircraft track, the mean of the $\Delta InL_{i,i+1}$ is 6.4ms, and the standard deviation of $\Delta InL_{i,i+1}$ is 45ms. Then, the estimated standard deviation of *InL* is 32ms. If aircraft is flying at the speed of 400knots, 32ms deviation is equal to 6.60meters position error. In this case, the estimated position error of this aircraft is small.

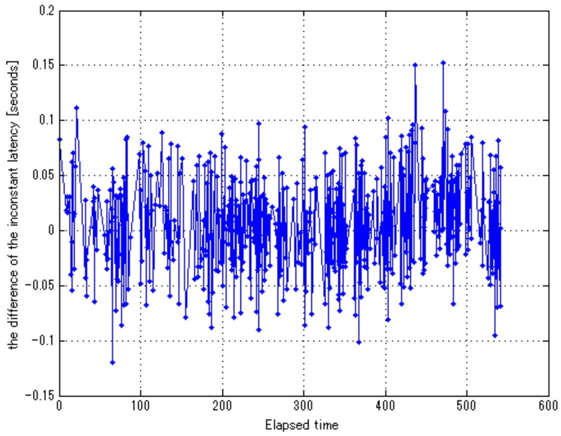

Figure 3. The difference of the inconstant latency $\Delta InL_{i,i+1}$

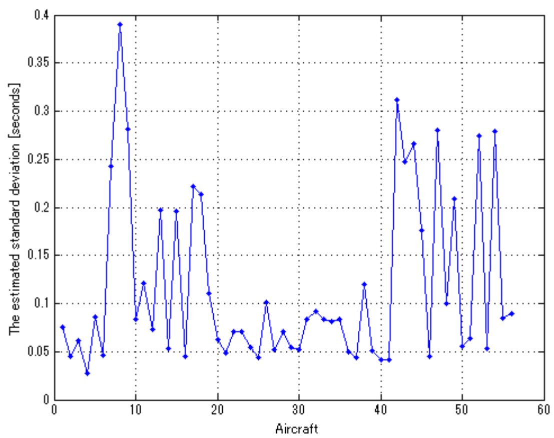

Figure 4. The estimated standard deviation of these aircraft

We also compute the standard deviations for different 56 aircraft as shown in Fig. 4. The x-axis shows the number of aircraft, and the y-axis shows estimated standard deviations of the inconstant latency.

36 out of 56 aircraft were within 0.1seconds. These deviation is mainly caused by the transmitting jitter at the transmitting phase.

12 aircraft were more than 0.2 seconds. This large deviation may be caused by the irregular operations in onboard ADS-B systems. So far, the mechanism of this deviation is under investigation.

5. CONCLUSION

In this paper, we propose a technology to estimate the ADS-B latency, and apply this technology to real data obtained by ENRI experimental system.

We have two conclusions. First, by the proposed technology, we find the inconstant latency of the majority of aircraft is within 0.1 seconds. Second, by the proposed technology, we find that some aircraft are transmitting ADS-B positions with large error.

In the future works, we are going to investigate the cause of the second result.

6. REFERENCES

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