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Proposed New Appendix on Timing

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Total Latency and Uncompensated Latency in ADS-B

Introduction

The total latency of position information is the delay between the time of applicability of the position measurement and the time of transmission of that position. Delay may be compensated for by advancing the position in the direction of travel. The uncompensated latency of position information is that portion of total latency that is not (or will not be) compensated for. When the ADS-B transmitting subsystem is synchronized with the position source, uncompensated latency can essentially be eliminated by setting the TIME (T) bit equal to ONE ("1") (see section 2.2.3.2.3.7, 2.2.3.2.4.7). Without synchronization, uncompensated latency is introduced by unknown delays in the data stream. In this case, the requirements in section 2.2.3.2.3.8 and section 2.2.3.2.4.8 control the contribution to uncompensated latency by the ADS-B transmitting subsystem.

Description of the Problem

The functional architecture of a transmitting aircraft is depicted in Figure 1.

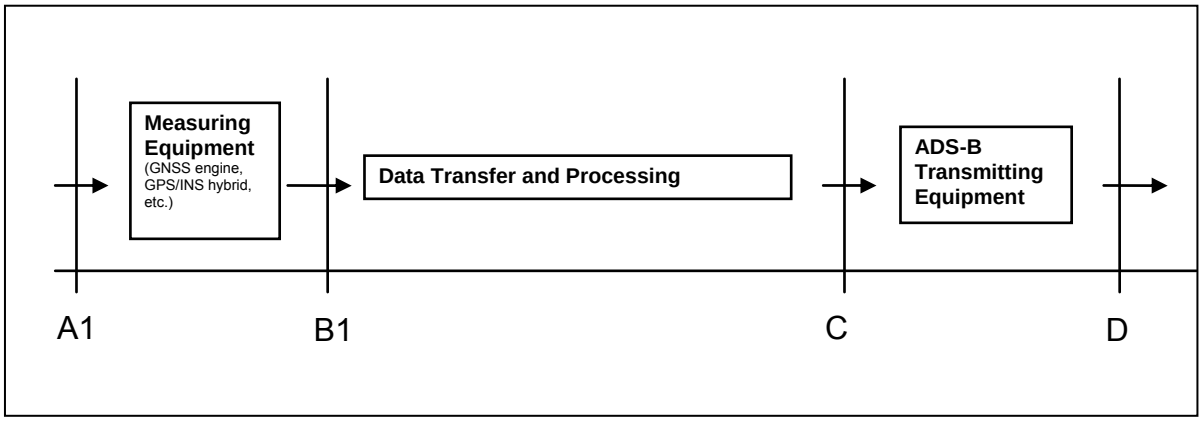

Figure 1: Functional Architecture Diagram

The interfaces are defined as follows:

- A1: Input to the Measuring Equipment
- B1: Output of the Measuring Equipment
- C: Input to the ADS-B Transmitting Equipment
- D: Output of the ADS-B Transmitting Equipment (i.e. the transmission)

Timing Notation

Any absolute time defined below is with respect to a common frame of reference. For simplicity, the timescale can be assumed to be GNSS time.

For a piece of data in the stream and an interface X, let T_X be the time that the data crosses interface X. Let TOA_X be the true time of applicability of the data that crosses interface X. It is emphasized that TOA_X represents the truth—i.e. it is the ideal time of applicability of the data at interface X.

In the case of position data, as it moves through the data stream it may be advanced in the direction of travel to compensate for timing. For interfaces X and Y define $\Delta T_{X \to Y}$ to be the total amount of time compensated for by the equipment between interfaces X and Y.

Key examples of this notation are listed below:

- For a GNSS position source TOA_{B1} is the time mark or appropriate GNSS epoch, and this is the ideal time of applicability.
- The GNSS industry standard is a not-to-exceed value of $T_{B1} - TOA_{B1} < 200$ ms.
- Extrapolation is not usually performed on the position between interfaces B1 and C i.e., $\Delta T_{B1 \to C}$ is usually zero and $TOA_C = TOA_{B1}$.
- $\Delta T_{C \to D}$ is the total amount of extrapolation performed by the ADS-B Transmitting Equipment.

The general timing diagram is presented in Figure 2:

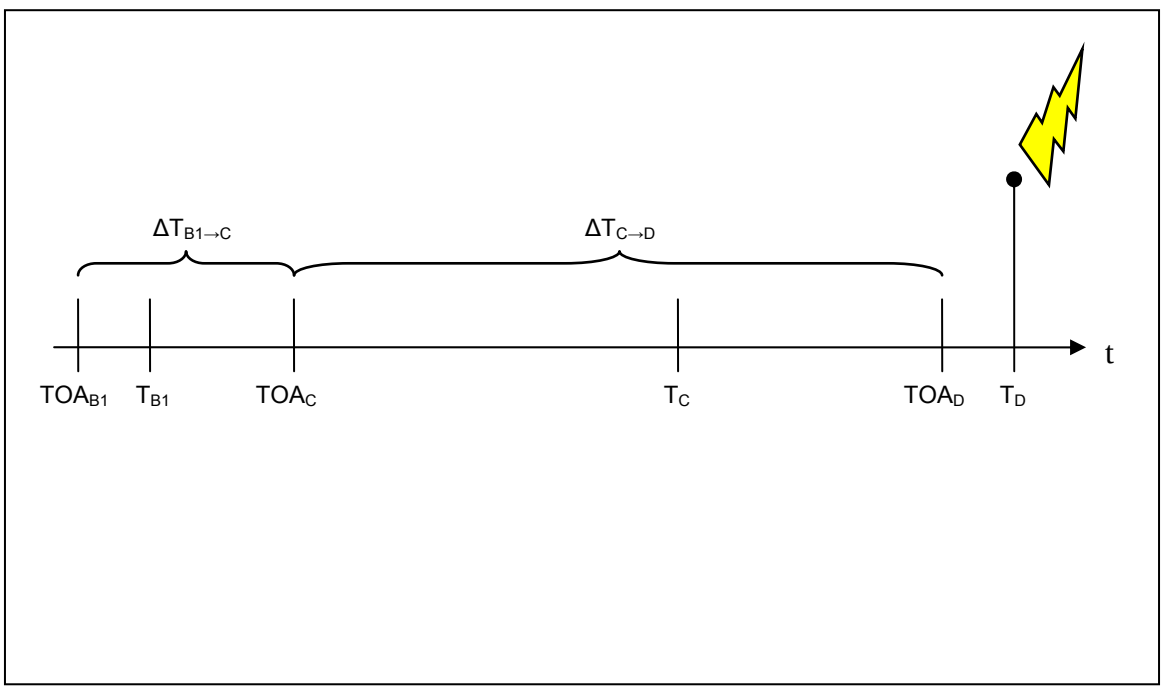

Figure 2: The general timing diagram

Lastly, let $TTOA$ be the transmit time of applicability. The value of $TTOA$ is the time that is expected to be decoded by the ADS-B Receiving subsystem as being the time to which the position contained in the ADS-B Airborne or Surface Position Message is accurate. Position extrapolation is performed within the ADS-B Transmitting subsystem so as to minimize the error in $TTOA$. The transmit time of applicability varies according to the T-bit:

- When the T-bit is set to zero, the receiver takes the time of applicability of the received data to be the time of reception, so $TTOA = T_D$.
- When the T-bit is set to one, $TTOA$ is the appropriate 200 ms GNSS epoch, determined by the CPR (F) bit and the time of transmission as per section INSERT SECTION HERE.

The processed time of applicability, $PTOA$, is the time of applicability of the data being transmitted as understood and processed by the ADS-B Transmitting subsystem. Essentially, $PTOA$ is an estimate of TOA_D, and as such its value depends on the level of knowledge that the ADS-B Transmitting subsystem has regarding the true time of applicability of the position data received over interface C, TOA_C. Consequently, the performance of $PTOA$ is dependent upon the T-bit:

- ~~When the T-bit is set to zero, it may be assumed that the ADS-B Transmitting subsystem does not have the GNSS time mark and will, at least implicitly, make some assumptions about TOA_C when extrapolating position information for transmission. Let $\overline{TOA_C} \approx TOA_C$ be the estimate of TOA_C employed by the ADS-B Transmitting subsystem. According to the requirements in section INSERT SECTION HERE, the minimum implementation must take the time of applicability of the data received over interface C to be no later than the time that the data crosses interface C. In other words, the minimal assumption is that $TOA_C \approx \overline{TOA_C} - T_C$. In general, it is possible for an implementation to attempt to compensate for known delays prior to interface C, thus making a more accurate assumption that $TOA_C \approx \overline{TOA_C} - T_C - \Delta T$. Here ΔT is an estimation of $T_C - TOA_C$, the uncompensated delay between the time of applicability of the position fix and the delivery of that position fix to interface C. Thus ΔT represents a one-time compensation performed by the ADS-B Transmitting subsystem. Note that by definition ΔT comprises a portion of $\Delta T_{C \to D}$, and in the minimal implementation, $\Delta T = 0$. In the case when the T-bit is set to zero, the processed time of applicability ($PTOA$) is the estimated time of applicability of the data crossing interface C ($\overline{TOA_C}$) plus the amount of compensation performed by the ADS-B Transmitting subsystem. In other words, $PTOA = \overline{TOA_C} + (\Delta T_{C \to D})$.~~
- ~~When the T-bit is set to one, $PTOA$ is the appropriate 200 ms GNSS epoch, determined by the CPR (F) bit and the time of transmission. The requirements in~~

~~sections 2.2.3.2.7.2, 2.2.3.2.8.2, 2.2.4.2.7.2, and 2.2.4.2.8.2 imply that extrapolation is performed such that $PTOA = TOA_D \pm$ clock errors.~~

Latency Definitions

Total Latency (TL) is the amount of time taken to broadcast a position relative to the time of applicability of the position measurement. Using the above notation,

$$TL = T_D - TOA_{B1}.$$

In order to compensate for this delay, the position data may be advanced in the direction of travel at a rate based on current velocity. Uncompensated Latency (UL) is the amount of Total Latency that is not or can not be compensated for by the receiver. In other words, it is the difference between the time of applicability understood by the receiver and the true time of applicability of the transmitted data:

$$UL = TTOA - TOA_D$$

$$= TTOA - (TOA_{B1} + \Delta T_{B1 \to D}).$$

As TOA_D is truth data, Uncompensated Latency is simply the error in $TTOA$.

- For non-GNSS coupled transmissions, $TTOA = T_D$. So,
  $$UL = T_D - (TOA_{B1} + \Delta T_{B1 \to D}) = TL - \Delta T_{B1 \to D}.$$
  Intuitively, Uncompensated Latency is Total Latency minus the amount of compensation performed.
- For GNSS-coupled transmissions, Uncompensated Latency is on the order of clock errors and is considered negligible.

Uncompensated Latency

In the case of GNSS-coupled Airborne and Surface Position messages, uncompensated latency is negligible.

For non-GNSS coupled transmissions, requirements in section 2.2.3.2.3.8 and section 2.2.3.2.4.8 can be stated precisely as $|(T_D - T_C) - \Delta T_{C \to D}| < 100$ milliseconds. This ensures that most of the delay incurred by the ADS-B Transmitting subsystem is compensated for, but there are two other components of Uncompensated Latency.

- The delay between the time of applicability of the measurement made by the measuring equipment and the time that the data is delivered across interface B1, $T_{B1} - TOA_{B1}$. In the case of GPS/GNSS equipment, this value is limited to no more than 200 milliseconds. It is recommended that non-GNSS measuring equipment used to provide data to the ADS-B Transmitting subsystem meet the same timing performance to be equivalent.

- The uncompensated delay between the time that the data is delivered across interface B1 and the time that the data is provided to the ADS-B Transmitting subsystem through the data interface C, i.e., $(T_C - T_{B1}) - \Delta T_{B1 \to C}$. There is currently no standard limiting $T_C - T_{B1}$, and $\Delta T_{B1 \to C}$ is zero in every fielded installation. The expected aircraft installation is one for which the position source is directly wired to the ADS-B Transmitting subsystem, or equivalent. Excessive delays caused by data routing or queuing are undesirable, though in principle these delays can be compensated for by the equipment between interfaces B1 and C. Installations should not be permitted for which $\left|(T_C - T_{B1}) - \Delta T_{B1 \to C}\right|$ exceeds 100 milliseconds.

The MOPS requirements and these recommendations lead to an uncompensated latency budget of $-200 < UL < 400$ milliseconds in the case of T=0.

Total Latency

It is recommended that Total Latency be limited to 1.5 seconds.