RTCA Special Committee 186, Working Group 5

ADS-B UAT MOPS

Meeting #10

Draft 2 of Appendix I:
UAT Timing Requirements

Presented by Chris Moody and Tom Mosher

SUMMARY
This is Draft 2 of a proposed Appendix I, whose purpose is to document the expected total installed end-to-end timing performance as guidance to UAT installers and to developers of ADS-B validation applications, and to provide rationale for the timing related requirements given in the UAT MOPS in the context of the expected total installed performance. This draft includes an update of material previously published as UAT-WP-9-08.

Appendix I
UAT Timing Requirements

I.1 Background

This UAT MOPS contains timing requirements related to both the transmission of ADS-B messages and reception of ADS-B and Ground Uplink messages. These requirements are intended primarily to support applications that use knowledge of the precise Time of Message Transmission (TOMT) and Time of Message Receipt (TOMR) to determine a range to the ADS-B transmitter. An *ADS-B validation* application can compare this one-way time of propagation range measurement with the range determined from the ADS-B message to increase confidence that the message came from a bona fide transmitter.

This ADS-B validation procedure is only available in cases where both the transmitting and receiving stations are *UTC coupled*, that is, they are receiving time from a GPS/GNSS source or equivalent. This UAT MOPS allows for GPS/GNSS timing sources that are either *external* or *internal* to the UAT equipment. Whether the timing source is external or internal, the UAT MOPS requires UTC coupling as the normal operational condition. A non-UTC coupled condition can occur due to a temporary unavailability of the GPS/GNSS source or equivalent. At any given time, a UAT transmitter is obligated to announce whether or not it is in the UTC coupled state.

I.2 Purpose

The purpose of this Appendix is not to design or specify an ADS-B validation application. Instead, the purpose of this Appendix is the following:

1. Document the expected total installed end-to-end timing performance as guidance to UAT installers and to developers of ADS-B validation applications.
2. Provide context for the timing related requirements given in this MOPS in the context of the expected total installed performance.
3. List additional considerations for developing an ADS-B validation application.

I.3 Installed End-End Timing Performance

Listed below are the identified components of possible timing errors and their assumed worst-case values using a GPS/GNSS source as an example.

a) <u>Errors due to the GPS signal in space</u>: This is assumed bounded by the performance specifications of the GPS Standard Positioning Service with SA OFF. Uncertainty range ~-100**to +100 ns**.
b) <u>GPS antenna and coax effects</u>. This is assumed bounded by a 20 meter maximum installed cable length. Uncertainty range = **-0 to +66 ns**

c) GPS-UTC time offsets: This is applicable to GPS receivers that output GPS time instead of UTC time. Since GPS sensors that may be used for ADS-B are not required to make the UTC correction, this offset must be included. GPS specifications allow GPS time to deviate from UTC time by up to 1 microsecond. This is expected to be very conservative since most aircraft installations will likely be on GPS time. Uncertainty range = **-1000 ns to +1000 ns**.

d) Delays due to interconnection of GPS sensor and UAT: This component applies to installations with external UTC coupled time source. Allowance is needed for delays induced in lightening protection filters and interconnect cable capacitance between the GPS/GNSS sensor and the UAT. Total uncertainty range based on tests has been determined to be = **-0 to +800 ns**.

e) UAT Tx/Rx time errors: errors due to control of transmitter turn on and in marking message time of arrival within the receiver. An uncertainty range specifically for this component is established in this MOPS. . Uncertainty range = **-500 ns to +500 ns**.

f) UAT antenna/coax effects: This is assumed bounded by a 20 meter maximum installed cable length. Uncertainty range = **-0 to +66 ns**

While some of the timing errors are of a fixed offset nature, it was determined that any form of timing calibration procedure required of the UAT system installer would be impractical.

The figures below show the components of the total end-end timing uncertainty relative to the installed equipment for both cases. The first case is where the GPS/GNSS sensor is internal to the UAT. The second case is where the GPS/GNSS sensor is external to the UAT.

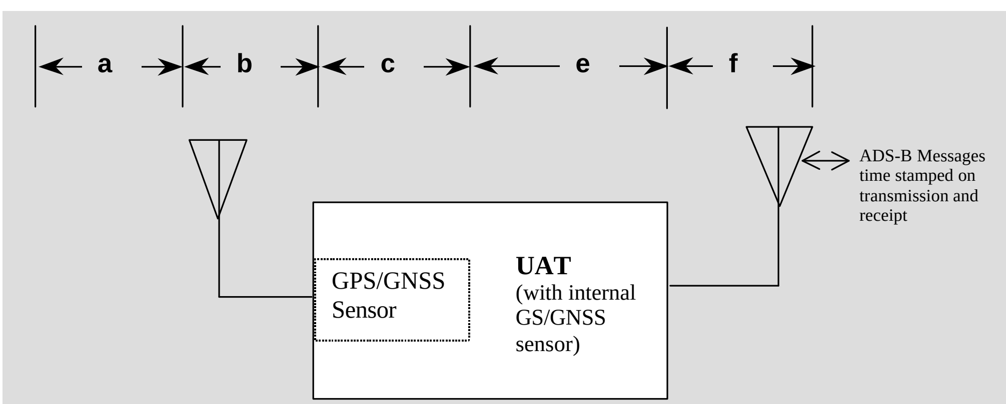

Figure I-1: Components of the Timing Error Budget--Internal UTC Coupled Time Source

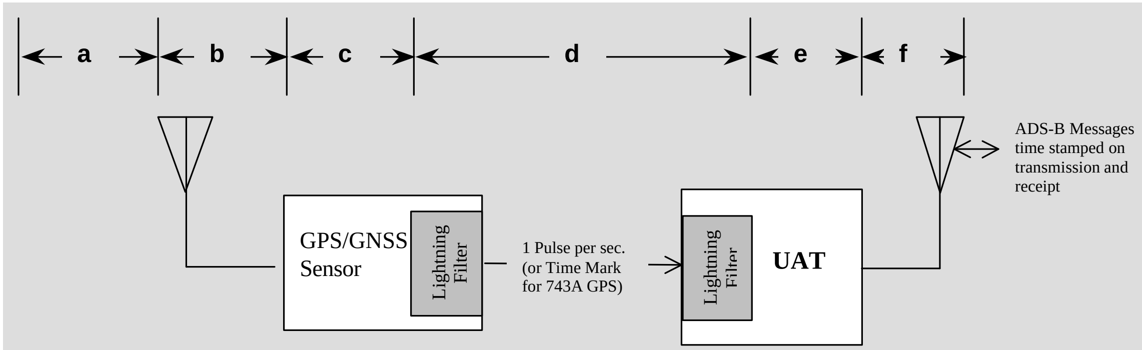

Figure I-2: Components of the Timing Error Budget--External UTC Coupled Time Source

Table I-1 below shows the worst case timing offset possible between a transmitting UAT and a receiving UAT given the individual error components listed above. This suggests that a value just under 0.7 nmi would represent the absolute worst case range error due to timing offsets between transmitter and receiver under normal (UTC Coupled) conditions.

Table I-1 Transmitter to Receiver Time Offset Worst Case

<table>
<tr><th>Error Component</th><th>Maximum Early (ns)</th><th>Maximum Late (ns)</th></tr>
<tr><td>a)</td><td>-100</td><td>+100</td></tr>
<tr><td>b)</td><td>-0</td><td>+66</td></tr>
<tr><td>c)</td><td>-1000</td><td>+1000</td></tr>
<tr><td>d)</td><td>-0</td><td>+800</td></tr>
<tr><td>e)</td><td>-500</td><td>+500</td></tr>
<tr><td>f)</td><td>-0</td><td>+66</td></tr>
<tr><td rowspan="2">Total worst case combination of all components</td><td>-1600</td><td>+2532</td></tr>
<tr><td colspan="2">Total transmitter to receiver offset with each at worst case individually = 4132 ns</td></tr>
<tr><td>Resulting maximum range error</td><td colspan="2">~ 0.66 nmi</td></tr>
</table>

For comparison, note that if Internal UTC coupled time is present on both the transmitter and receiver, and more typical UTC offsets (~100 ns) are present, then the nominal time error would be less than 1600 ns, or about 0.25 nmi. If there is some operational advantage to this higher level of range measurement accuracy, then it may be useful to include a data bit in the transmitted payload and report format that convey the accuracy of the timing reference.

I.4 MOPS Timing Requirements

There are essentially two UAT MOPS requirements related to timing: one related to control of ADS-B message transmission, and one related to time stamping of message receipt. The requirements and test conditions are treated separately depending on whether the UTC coupled time source is internal or external. Timing requirements in this MOPS are specifically limited to items that are testable independent of any other installed equipment.

Message Transmission Timing:
The MOPS section on “Relationship of the MSO to the Modulated Data” specifies the requirement for ADS-B message transmission timing.

- When an internal UTC coupled source time source is used, the requirement and test is designed to verify uncertainty components c) *(GPS-UTC)* and e) *(UAT Tx time)*. This is accomplished by applying an actual or simulated GPS input to the UAT such that the GPS signal presents minimal timing uncertainty. The maximum timing error allowed is 500 ns.
- When an external UTC coupled time source is used, the requirement and test is designed essentially to account only for part of component d) *(GPS interconnection delays)* and component e) *(UAT Tx time)*. This is accomplished by applying a test 1PPS or Time Mark input that is essentially free of uncertainty components a), b), c), and most of d). The maximum timing error allowed is 500 ns.

Accuracy of Time Stamping on Message Receipt:
The MOPS section on “Time of Message Receipt” specifies the requirement for time-stamping of received messages.

- When an internal UTC coupled source time source is used, the requirement and test is designed to verify uncertainty components c) *(GPS-UTC)* and e) *(UAT Rx timestamp)*. This is accomplished by applying an actual or simulated GPS input to the UAT such that the GPS signal presents minimal timing uncertainty. The maximum timing error allowed is 500 ns.
- When an external UTC coupled time source is used, the requirement and test is designed essentially to account only for part of component d) *(GPS interconnection delay)* and component e) *(UAT Rx timestamp)*. This is accomplished by applying a test 1PPS or Time Mark input that is essentially free of uncertainty components a), b), c), and most of d). The maximum timing error allowed is 500 ns.

I.5 Considerations for ADS-B Validation Applications

Time of Message Receipt (TOMR)
The MOPS details the requirements for accuracy and resolution of making the raw measurements on which a range calculation can occur. TOMR is relative to the start of the UTC second, and typically is measured in units of 100 nanoseconds.

The UAT receiver or an external application can directly calculate the range to the target by knowing how many whole and fractions of an MSO (250 usec) of time elapsed between transmission and receipt of the message. The fractional portion is directly calculated from each SV report received, which gives fine-scale resolution to about 30 meters (100 ns times 3.0e+8 m/s). The integer portion provides resolution of about 40.47 nm (250 usec times 3.0e+8 m/s)

Acquisition of full TOMR Range

The full TOMR range (integer and fractional parts) can be determined once a Long message containing the Transmission Epoch report has been received (the Long Type 1 message). The Transmission Epoch field has sufficient span to unambiguously identify in which MSO the message was transmitted. The receiving UAT or the external application can then calculate the integer portion of TOMR, and derive of the full TOMR value.

Once the full TOMR range has been acquired, the fractional portion can be used to maintain a track of the range value during the interval between receipts of a report containing the Transmission Epoch.

TOMR Range Filtering

Due to plant noise and other physical effects, one can expect the raw TOMR range values will require some filtering prior to use. An alpha-beta recursive filter can be used to both smooth and predict range values, which allows for uneven time between message receptions (due to dropped messages, etc.).

Correlation of TOMR Range vs. SV-based Range.

Slant Range: The filtered range value includes the slant range effects, and will normally exceed the great-circle range calculated from the SV position of the target and the ownship SV position. The correlation of the target's range will require either some compensation of the great-circle range to include an estimate of the slant range, or a correlation window that has greater tolerance for increased slant range at high elevation angles. Since it is possible that some targets may not be reporting their altitude, provision must be made for cases where slant range compensation is not possible.

Datalink latency: One other effect of the TOMR range calculation is that the range measured is based on the time of transmission, while the SV-based range calculation is based on the report time of applicability. This can lead to some additional variation between the measured and calculated range, which would be particularly noticeable in head-on or reciprocal encounters at high velocity. For example, at a closing rate of 1200 kts, the range closes at about 620 meters per second. The range differential amounts to at most 0.33 nmi.

Note that for a given pair of aircraft, most of the timing errors can either be compensated for, or are fixed intervals. This allows the possibility that the residual range differential (after removal of fixed or compensate-able errors) could be used as an independent means of closure rate measurement.

Anti-Spoofing

The MOPS does not address what to do in the case that the target's TOMR range cannot be correlated with its great-circle range. Other than flagging the target to alert the host application (e.g. CDTI or ATC surveillance) that there is some question as to it's veracity, it is not obvious what further appropriate action would be. There is probably no expectation in the CDTI working groups that they would be required to depict the range integrity of a target. Neither does it seem proper to exclude a potentially conflicting target from the traffic report bus based on a non-correllated range measurement. Perhaps certain pairwise procedures would only be authorized when the opposing target passes some range validation criteria.