S-AIS Timing Errors and Correction

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Abstract—**Timing errors can badly affect the association between ship detections derived from high resolution space-borne radar and the position reports from AIS signals. Of particular interest are those S-AIS reports received by satellites. For S-AIS there are three relevant types of clock: the clock on the satellite carrying the AIS receiver, the clock used by each ship AIS transponder and the clock on base stations. Errors can occur in the times from all clock types. We describe procedures to monitor the timing accuracy of the satellite clock, to correct minor errors in the satellite clock and to verify the times.**

Index Terms—**AIS, timing error, association.**

I. INTRODUCTION

TIMING errors can badly affect attempts to associate the position of a ship derived from satellite-borne radar and the positions extracted from independent satellite-borne AIS receivers (S-AIS). For example, when a ship moves at 30 knots, a timing error of one minute effectively translates into an AIS position report error that can be slightly less than a kilometer. While this is often not important when the shipping density is low, it can easily defeat association algorithms in a high shipping density environment. Association between AIS and radar targets depends on identifying the ship that transmitted the AIS signal with a target in a radar image.

The existence of significant errors is puzzling as one might have expected all AIS clocks to be synchronized to the Global Positioning System (GPS) or an equivalent and to be accurate at least to one second. However, significant timing errors seem to occur quite often in the satellite clocks and in the clocks from transponders and base stations [1]. From S-AIS data providers, the time from a satellite clock is generally expressed as a UTC date and time at least to the nearest second. In contrast the time in a ship position report depends on the transponder clock but this is usually expressed only in seconds. Therefore it is not always possible to detect serious disparities between the satellite clock and a transponder clock that are more than a minute. Nevertheless, a comparison between the satellite time and a transponder time usually indicates that the two clocks agree to within a few seconds.

The problem of the limited range of the UTC time in the position reports can be overcome by referring to the base station reports, which are sent periodically in AIS message ID number 4; base stations are typically coastal stations operated by a regional maritime authority. The number of message 4 reports in the present data-set ranges between a few hundred to over 1000 per hour [2].

Message 4 includes the base station Maritime Mobile Service Identity (MMSI) number, the station latitude and longitude and the full UTC time including the date. This allows a detailed comparison with the satellite clock. Usually the satellite and base station clocks agree within a few seconds but sometimes the base station time is clearly erroneous. For example, some base station clocks are obviously inoperative and the year is incorrect and sometimes the base station clock is in error by several seconds or even a minute.

The data stream from a data provider is typically ordered chronologically except that data from different satellites tends to occur in blocks and these sometimes overlap in time. Therefore sorting in time is usually required as a part of the processing. Different satellites may receive the same AIS signals from a ship or base station and this allows a direct comparison of the satellite clock times. The AIS signals are characterized by their transponder clock times and by their MMSI numbers and position so that it is straightforward to locate the same signals received by different satellites. When the satellite times are different (even by a second), as is frequently the case, there is only one reasonable conclusion: one or both satellite clocks are inaccurate.

The data stream typically includes a variety of reports from different base stations scattered over a wide area. The likelihood of significant correlation between timing errors from each base station clock is very low. Therefore the timing errors can be regarded as random. If there is an occasional large difference between the satellite clock and a base station clock, it is likely that the error is in the base station time. In contrast, if there is a sequence of large differences between the satellite clock and the base station clocks (such as approximately a minute, which sometimes happens), then the problem is almost certainly associated with the satellite clock.

This behavior permits the correction of the satellite clock to remove systematic errors. It relies primarily on a comparison of satellite and base station times and can be augmented secondarily by a comparison between satellite and ship transponder times. This latter comparison can be regarded as a verification process. Firstly, for each block of data from a single satellite, persistent runs of satellite clock errors must be identified. If these errors are approximately an integer number

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of minutes, the satellite clock must be corrected by the integer number of minutes. Otherwise the data must be rejected. Secondly it is necessary to remove any base station reports that exhibit large errors of more than a few seconds; this includes residual (after correction) time shifts of an integer number of minutes. Thirdly, the remaining data should be analyzed to determine the systematic and random errors represented by the mean and standard deviation of the timing correction to the satellite clock.

The corrected satellite clock times can now be compared to the times from ship transponders in message 11 as well as the UTC seconds from normal ship position reports. If the corrections are satisfactory, there should be a minimal difference in the means that is more or less consistent with the standard deviations found from the base station report comparison and the transponder timing error statistics. In principle the significance of differences can be assessed using a null hypothesis statistical test. This constitutes verification of the timing.

Details of the formats of the various messages can be found in [3].

II. STATISTICS

A data set processed by exactEarth was provided by the Canadian Space Agency. This contained signals received from ships around the globe by various satellite-borne receivers for the month of March 2013. All 27 types of AIS message were included and in particular the class A and B position reports and the base station reports (message 4).

Computer code was written to extract all records in which the base station MMSI and the transmission time were identical but the satellite IDs were different. Table 1 contains examples of AIS information received simultaneously by two satellites from March 3rd 2013. This illustrates the variability of the satellite clocks. In the first two records of the table, the clocks almost agree. However in the remaining records, the clock on satellite with ID “1” is about a minute ahead; the clocks on satellites with IDs “2” and “53” remain reasonably accurate.

Similarly Table 2 contains data for October 2nd 2013. Again the clock of the satellite with ID “1” is approximately a minute ahead of the other clocks, notably that of satellite “56”.

A plot of the difference between the times of messages according to the provider and the times of base station reports (message 4) as a function of satellite time is shown in Figure 1 for satellite “80”; this is for a situation in which there are no large errors during March 1st 2013. Errors are positive when the transponder time is ahead of the satellite time. There appears to be evidence of a trend.

Similarly Figure 2 and Figure 3 show the errors for satellites 1 and 2. In the last case there are a few quite large errors.

Default times are often transmitted by base stations that indicate that the clocks are not operational. These represent about 11 percent, 5 percent and 5 percent for satellites “80”, “1” and “2” respectively.

Apart from errors of many seconds, timing discrepancies are likely to be associated at least in part with the base station clocks because frequent abrupt changes in the satellite clock times are not expected.

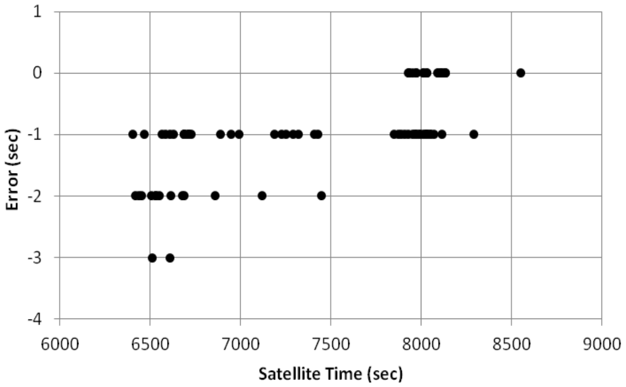

Figure 1. Satellite 80 timing errors.

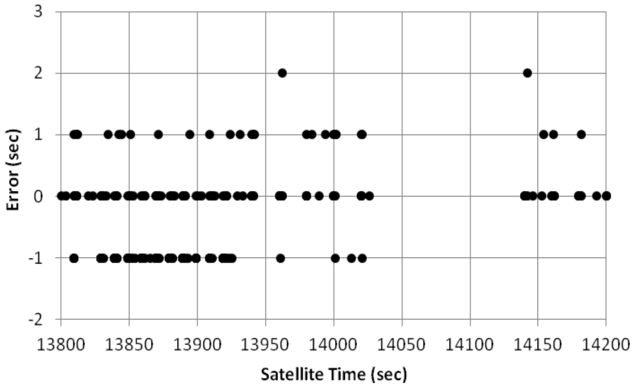

Figure 2. Satellite 1 timing errors.

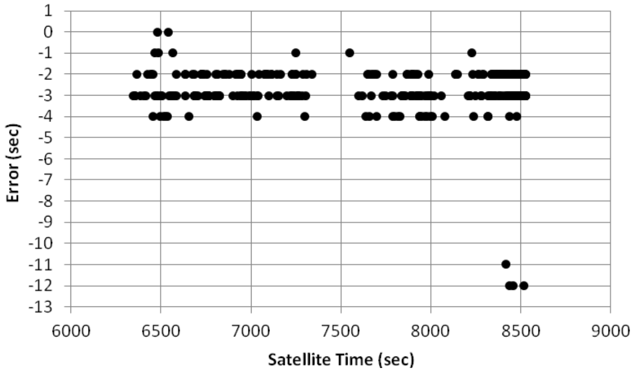

Figure 3. Satellite 2 timing errors.

Histograms of the errors are presented in Figures 4 to 6. The data set employed in the following figures each represents about 5 hours of receiver time. In the case of satellites “80” and “2”, the errors tend to be limited to a range of 4 seconds but for satellite “1” there are large errors of about a minute. Also there is a large proportion of such errors.

It is evident that the satellite times from the provider tend to lag the base station transponder times by about a second and that, at least when the errors are benign as in Figures 4 and 6, the distribution is approximately normal (i.e. Gaussian). The distribution of the mean error is therefore close to normally distributed and, if the number of samples is of the order of 1000, its standard deviation is about 0.1 seconds.

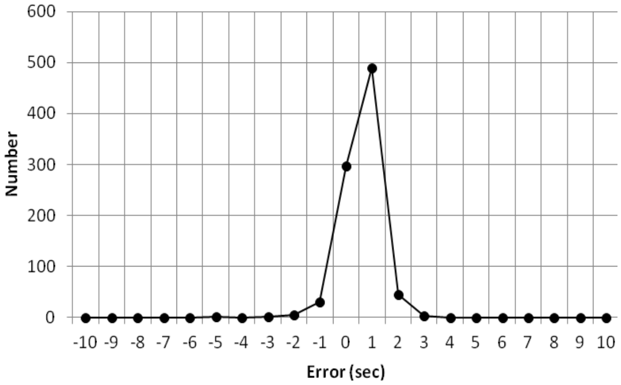

Figure 4. Histogram of errors for satellite 80.

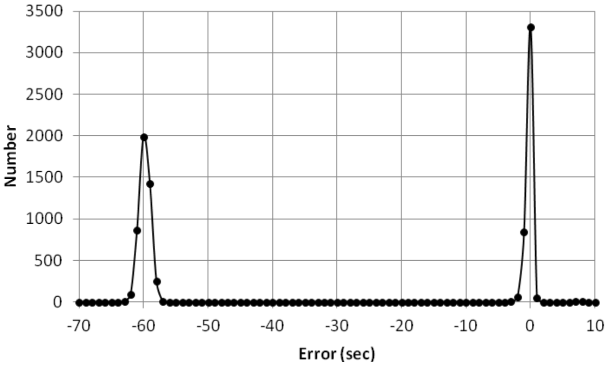

Figure 5. Histogram of errors for satellite 1.

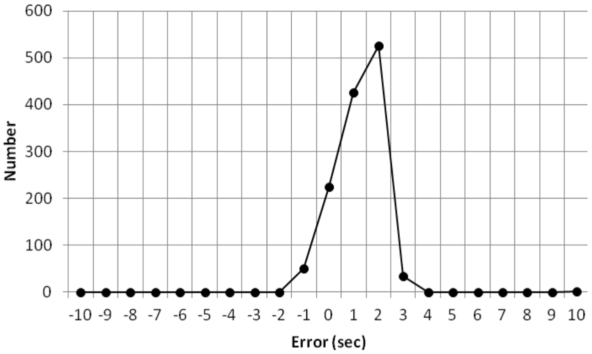

Figure 6. Histogram of errors for satellite 2.

Message 11 is transmitted by ship transponders in response to an interrogation using message 10. However, the number of message 11 reports is two orders of magnitude lower than the number of message 4 reports. Therefore, to generate a histogram of errors, the satellite data are combined. The result is shown in Figure 7; the dispersion appears to be similar to that of the base station timing errors using message 4. In this particular data there were no large additional errors of an integral number of minutes.

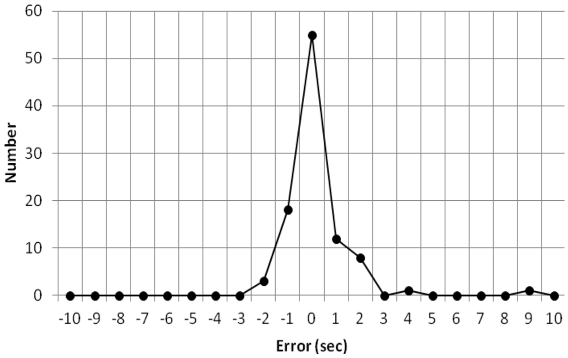

Figure 7. Histogram of errors for message 11: all satellites.

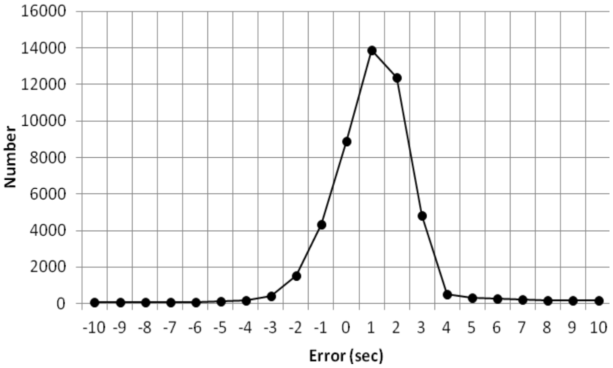

Figure 8. Histogram of errors for message 1: satellite 80**.**

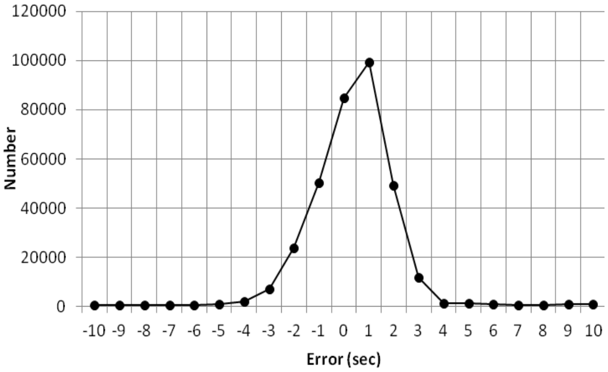

Figure 9. Histogram of errors for message 1: satellite 1.

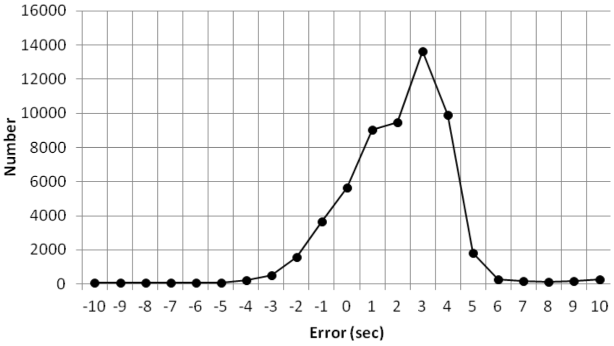

Figure 10. Histogram of errors for message 1: satellite 2.

It was hoped that the data from (Class A) message 1 might be useful for verification purposes. The histograms for this can be seen in Figures 8, 9 and 10, which are derived from about 5 hours of data on March 1st 2013. It is clear that the dispersion is somewhat larger than that for the base stations or even from the ships that have been interrogated. Perhaps this should have been expected because the base stations are operated or administered by competent maritime authorities. However, there are many more message 1, 2 and 3 reports than there are message 4 reports so that the dispersion of the means are comparable and it should indeed be possible to use the position reports for verification purposes.

There are also differences in the histograms that are probably due to the different orbital coverages by the various satellites. Therefore the details of the means and standard deviations will not be pursued here.

III. CONCLUSION

By analyzing the reports from base stations that are received simultaneously by different satellites, it is clear that there are timing errors in the satellite clock data typically of a few seconds. Occasionally there are additional errors of a minute. These additional errors tend to take place persistently and are then corrected by the provider. They occur sufficiently often to be troublesome when the data is used operationally for maritime surveillance and the shipping density is high. This is because they can lead to positional errors relative to ship detections based on radar of up to a kilometer.

Fortunately the additional errors of a minute can be corrected without simultaneous satellite reception because of their persistence. There remain the errors of the order of a second.

Timing errors of a few seconds are irrelevant in low shipping densities. They could still have an impact on the association performance in high shipping densities. This is because they translate into positional errors of a few meters and this could be important when ships are separated by less than a few hundred meters.

It is strongly recommended that satellite timing be monitored continuously using messages 4 as well as the position reports (Class A) and that appropriate corrections be applied. It is noted that the timing information can sometimes contain the hour and minute in the fields of the communications state within messages 1, 2 and 3. Class B reports are not regarded as sufficiently frequent or reliable.

REFERENCES

[1] Harm Greidanus, *Private communication*, September 2013.

[2] J.K.E. Tunaley, "The Utility of Various AIS Messages for Maritime Awareness", Canadian Space Agency ASAR-2013 Workshop, October 2013; at www.London-Research-and-Development.com.

[3] *Technical characteristics for an automatic identification system using time-division multiple access in the VHF maritime mobile band*, ITU-R M.1371-4, April 2010.

Table 1
COMPARISON OF CLOCKS (MARCH 3RD 2013)

MMSI	Base Station UTC	Satellite # 1	Satellite #1 UTC	Satellite #2	Satellite #2 UTC
5030105	3:48:50	1	3:48:50	53	3:48:52
5030256	3:49:42	1	3:49:42	53	3:49:43
6170002	3:02:39	53	3:02:41	1	3:03:38
6170002	3:05:39	1	3:06:38	53	3:05:41
6170002	3:06:29	1	3:07:28	53	3:06:31
6170002	3:08:09	1	3:09:08	53	3:08:11
7010001	3:16:29	1	3:17:28	53	3:16:31
7010001	3:16:59	1	3:17:58	53	3:17:01
7010003	1:45:49	2	1:45:46	1	1:46:50
7010005	1:46:29	2	1:46:26	1	1:47:29
7010005	3:19:09	1	3:20:08	53	3:19:11
7010005	3:21:19	1	3:22:18	53	3:21:21
7010005	3:21:39	1	3:22:38	53	3:21:41
7550002	3:10:41	1	3:11:40	53	3:10:43
7550002	3:14:44	1	3:15:43	53	3:14:46
7550002	3:16:44	1	3:17:43	53	3:16:46
7550002	3:17:44	1	3:18:43	53	3:17:46
7550002	3:19:44	1	3:20:43	53	3:19:46
7550003	3:18:41	1	3:19:40	53	3:18:42
7550003	3:20:24	1	3:21:23	53	3:20:25

Table 2
COMPARISON OF CLOCKS (OCTOBER 2ND 2013)

MMSI	Base Station UTC	Satellite # 1	Satellite #1 UTC	Satellite #2	Satellite #2 UTC
2515033	3:05:45	56	3:05:44	1	3:06:42
5030134	2:10:21	1	2:11:20	56	2:10:20
5030134	2:10:41	1	2:11:40	56	2:10:40
5030134	2:11:11	1	2:12:10	56	2:11:10
5030150	2:10:23	1	2:11:22	56	2:10:22
5030150	2:10:33	1	2:11:32	56	2:10:32
5030150	2:11:03	1	2:12:02	56	2:11:02
5030190	2:07:40	1	2:08:39	56	2:07:39
5030190	2:08:00	1	2:09:00	56	2:07:59
5030190	2:10:20	1	2:11:20	56	2:10:19
5030190	2:10:40	1	2:11:40	56	2:10:39
5030190	2:11:10	1	2:12:09	56	2:11:09
5030190	2:11:20	1	2:12:19	56	2:11:20
5030190	2:12:10	1	2:13:09	56	2:12:09
5030190	2:12:50	1	2:13:50	56	2:12:50
5030204	2:08:40	1	2:09:40	56	2:08:39
5030204	2:10:20	1	2:11:20	56	2:10:20
5030204	2:10:40	1	2:11:40	56	2:10:40
5030204	2:12:10	1	2:13:09	56	2:12:09
5030230	2:12:09	1	2:13:09	56	2:12:09