Quality of AIS Services for Wide-Area Maritime Surveillance
Torkild Eriksen, Harm Greidanus, Marlene Alvarez, Domenico Nappo, Vincenzo Gammieri
European Commission – Joint Research Centre, Ispra, Italy

Abstract
The paper presents the ship tracking capabilities in the Maritime Situational Picture (MSP) built from non-classified AIS (Automatic Identification System) data from up to eight AIS satellites as well as terrestrial AIS. The results represent state-of-the-art of cooperative long-range capabilities.

During 2011–2013, the Joint Research Centre (JRC) of the European Commission has carried out two campaigns for counter-piracy surveillance under the name “Piracy, Maritime Awareness and Risks” (PMAR), each for 6-month; the first focussed on the seas off the Horn of Africa, the second on the Gulf of Guinea and West Africa. The AIS performance was analysed in terms of the number of ships tracked (up to 2 850 in the second campaign), the freshness (average maximum time gap between AIS messages over all ships was 4.4 h), the fraction of ships that are updated every 3 h (increased from 21% in January 2012 to 49% in March 2013), and other indicators.

The marginal value when adding data sources was analysed. For example, considering the data from the various AIS providers in March 2013, it is found that the average number of ships detected per day increased by 384 when increasing from one to two providers and by another 31 adding the third provider, whereas terrestrial AIS increased the number of ships with another 93. The average maximum time gap was reduced from 10.9 h to 4.4 h in steps of 1.9, 2.7 and 1.9 h. These results enable choices on how many satellites or data sources to use for a certain required performance.

1 Introduction
1.1 Objectives of the PMAR campaigns
Following a resolution by the European Parliament on piracy, the Joint Research Centre (JRC) of the European Commission (EC) has carried out two projects under the name Piracy, Maritime Awareness and Risks (PMAR) in the period 2010-2013. The projects have been funded by EC Directorate-General for Development and Cooperation – EuropeAid and coordinated with other activities of the EU and the global community on Regional Maritime Capacity Building for counter-piracy in Africa.

The PMAR projects use the Blue Hub, JRC’s in-house research and development platform for integrated maritime surveillance and maritime situational awareness, to assess technologies and methods and build a Maritime Situational Picture (MSP) on a real-time basis. The MSP is distributed as a web application as shown in Figure 1.1 (ship details are anonymised), that has been demonstrated to relevant national and regional authorities in piracy-affected regions, among others in the PMAR workshop in Mombasa [1]. The data sources assessed and used are the Automatic Identification System (AIS), Long Range Identification and Tracking (LRIT) and Vessel Detection System (VDS) based on satellite imagery, as presented in [2].
1.2 Objectives of the AIS data analysis

Whereas the PMAR projects and the MSP have been presented earlier, this paper presents the detailed analysis of the ship tracking capabilities obtained from non-classified AIS data from up to eight AIS satellites as well as terrestrial AIS. These results are relevant not only for the quality of the maritime picture built in the PMAR campaigns, but also as reference for the quality of service that can be obtained at regional level with today’s AIS satellites and partial coastal coverage of terrestrial stations.

2 The AIS system in brief

The AIS reporting requirements are outlined in Regulation 19 of Chapter V of the International Convention for the Safety of Life at Sea (SOLAS) [3]. Class A shipborne mobile equipment is mandatory for all passenger ships, tankers and other ships of 300 tons engaged in international voyages. The regulation states that AIS shall “provide automatically to appropriately equipped shore stations, other ships and aircraft information, including the ship’s identity, type, position, …”. Note however that the master of the ship has the right to switch off the AIS for the safety of the ship, which can apply during voyages in piracy affected areas.

The AIS system was developed as a ship-to-ship and ship-to-shore system, the technical and operational characteristics are outlined in the ITU Recommendation [4]. The reporting ships transmit short messages including the ship's Maritime Mobile Service Identity (MMSI) number, position, speed over ground (SOG), course over ground (COG) and the ship’s navigational status data and other voyage- and safety-related information. The reporting interval for the dynamic data (including MMSI,
position, SOG, COG) is 2 sec for speed > 23 knots, 6 sec for speed between 14 – 23 knots, 10 sec for speed below 14 knots, and 3 min for ships at anchor or moored and not moving faster than 3 knots. The messages are transmitted in timeslots of 26.7 msec, 2 250 messages per minute, on two channels giving a total of 4 500 messages/min within the coordination areas of the access mechanism. The default transmitter power is 12.5 W.

For class B equipment that is used voluntarily by pleasure craft, fishing boats and other vessels smaller than 300 tons the transmitter power is only 2 W, and the normally the shortest reporting interval when moving is 30 sec.

Today’s use of satellites to receive AIS messages (SAT-AIS) goes beyond the original intentions of the system, and was not considered when the access methods for allocation of time slots for the messages were decided. Before transmitting, the AIS transponders coordinate the allocation of time slots with other receivers within line of sight. This means that two or more transponders that cannot see each other can transmit at the same time, and the messages will arrive simultaneously at the satellite receiver. For simple receivers this means interference and limited possibility of receiving any message, whereas for advanced receivers it means the possibility of receiving several messages at the same time. The detection performance of current satellites and the future prospects of SAT-AIS have been presented and discussed in numerous papers, among others [5], [6], [7], [8].

3 The AIS data in the PMAR campaigns

The AIS data in the PMAR campaigns have been delivered by four providers; the first three are SAT-AIS providers whereas the fourth is a network of terrestrial stations placed in some ports and coastal areas:

- LuxSpace (LuxSp)
- exactEarth (eE)
- Norwegian Coastal Administration/Norwegian Defence Research Establishment (NCA/FFI)
- Maritime Safety and Security Information System (MSSIS)

Ship position reports of message type 1-3 (class A equipment) as well as 18-19 (class B equipment) are considered in this work.

Two PMAR campaigns have been carried out; the first off the Horn of Africa (for short referred to as the HoA) in the period 1st August 2011 – 31st January 2012, the second in the Gulf of Guinea and West Africa (referred to as the GoG) 1st October 2012 to 31st March 2013. Figure 3.1 shows ship tracks made from the dynamic AIS reports, for one day in the respective campaign periods.

In the HoA campaign in January 2012 the daily average number of messages received was 86 254 and the daily average number of ships was 1 294. The AIS data were received by eight platforms; three from eE, two from NCA/FFI, one from LuxSp up till mid-January and two in the last half of the month (VesselSat-2 launched 9th January), and to some extent the MSSIS network.

In the GoG in March 2013 the daily average numbers were 378 056 messages and 2 681 ships. The AIS data were also in this period received by eight platforms, however not the same as in January.
2012; the ExactView1 satellite from eE entered into operation in November 2012 but in March 2013 delivery of data from one of the old satellites was paused, hence the three eE satellites are different. The two NCA/FFI satellites and the two LuxSp satellites are the same. The MSSIS network is contributing more in the GoG- than in the HoA- campaign a year earlier.

Figure 3.1  Examples of daily traffic in the campaign areas; most recent ship position and track of the day. Left: HoA, 1326 ships, 18th January 2012. Right: GoG, 2699 ships, 25th March 2013. Background map courtesy of Google Earth.

4 Analysis of quality of service

4.1 Definition of performance figures

The quality of service (QoS) is studied on a daily basis in terms of number of received messages and observations as well as time between messages for each ship. An ‘observation’ is defined as an essential update of the ship position, as explained in the second bullet point below. The following performance figures are calculated for each ship, for each day:

- Number of messages per day ($n_{mes}$): the count of all messages from the queried providers.
- Number of observations per day ($n_{obs}$):
  - for SAT-AIS an observation is attributed to the first message in each satellite pass
  - for MSSIS an observation is attributed to a message received one hour after the previous observation.
- Number of hours per day with messages ($n_{hrs_w_mes}$): the number of the hourly histogram bins in the plot “messages per hour” that have a value greater than or equal to one.
- Maximum time gap ($dT_{max}$): the largest time gap between consecutive messages from any combination of platforms.
- Data older than 1 hour ($duration_{dT>1h}$): the total amount of time over the day during which the most recent message of a ship is older than 1 hour. Therefore, a figure that measures the absence of ‘fresh’ data. The 1st hour of the day is considered following the 24th hour to also include the gap before the first observation.
- Data older than 3 hours ($duration_{dT>3h}$): similar to the figure above, but aggregates the time during which the most recent message is more than 3 hours old.

For the calculation of the QoS in this chapter, data from all providers are used, whereas Chapter 5
gives an evaluation of QoS vs. the number of data providers. The number of observations and the temporal performance figures are calculated for each ship per day. Based on the figures for individual ships daily histogram distributions for all ships are made, as well as the daily averages for one week.

4.2 Observations of one ship during one day in March

Figure 4.1 shows the track of a selected ship on the 23rd March 2013. The performance figures for this ship are used to illustrate the method for calculation of the overall QoS for the maritime picture.

![Figure 4.1 Track of a selected ship on 23rd March.](image)

Figure 4.2 shows histogram plots of the number of messages received per hour (left) and the number of occurrences of time intervals between messages (right) of the selected ship. In this case all providers are queried, and the ship is detected by all seven satellite platforms, but not by the terrestrial network. It is evident from the plot that the messages typically come in bursts that make peaks and gaps in the diagram, but also that there is a possibility of detection outside the peaks. This is mainly due to the satellite orbits.

The performance figures are shown below the plots; \(n_{mes}=173\) messages are received, giving \(n_{obs}=27\) observations. The ‘Messages per hour’ plot shows that the messages have a fairly good spread over the day giving \(n_{hrs_w_mes}=17\). However, the height of the histogram bars shows that the distribution is uneven, from 0 to 40 messages are received per hour. The ‘Time between messages’ plot shows the distribution of the time between consecutive messages. The first histogram bin is from 0 – 0.5 hour. The gaps of this bin are those between messages received within one satellite pass and occasionally between messages received by two or more satellites that cover the area simultaneously; in this case the number is 159 gaps (the value is off-scale on the axis that goes to 100). The values 6, 6, 0, and 1 for the following bins represent gaps between messages of +/- 0.5 hour from 1-, 2-, 3- and 4-hours: Gaps are most often not more than 2.5 hours, only once it is between 3.5 and 4.5 hours, which is the maximum gap \(dT_{max}=3.59\) h. The total time per day the data of the selected ship is ‘old’ relative to an update interval of 1 hour is 7.29 h, whereas relative to the 3-hour requirement data is ‘old’ for 0.59 h.

To see how the observations (rather than the messages) are distributed over the day the histogram of observations per hour is shown in Figure 4.3. The graph shows that one observation is made in 11 of the hourly bins, more than one in six of the bins, and that the ship is undetected in seven bins.
Figure 4.2 Histogram of messages received per hour (left) and time between messages (right) for one ship on the 23rd March 2013.

Figure 4.3 Histogram plot of number of observations per hour over the day. The annotation shows the platform number and the detection time (UTC) of the first message in the pass.

The performance parameters below the plot are the same as in the plot of the time between messages. The plot annotations show what platform made the observation at what time (platform most often means satellite, but can also mean the MSSIS network; the platform numbers are internal identifiers of the Blue Hub system). The $dT_{\text{max}}$ is seen from 14:46 to 18:26. A calculation will show that this gap is 3.67 h (not 3.59 h), but then keep in mind that this is the time between what is defined as observations; the ‘Message per hour’ histogram shows that there are 6 messages belonging to the 14:46 observation, five of them arriving later the time attributed to the observation (14:46).

The observation time is a result of the satellite orbits. The slope of the annotation is proportional to the number of platforms contributing. Five of the platforms are in sun-synchronous orbits; hence they pass over at the same time every day. Further, the sun-synchronous orbits (in particular the nodes) are similar; hence the satellites pass over in the same time range. In this case it can be seen as the high number of observations between 10:27 and 13:09, as well as 12 hours earlier and later. Two platforms are in drifting orbits; hence the pass times vary from day to day, and these satellites fill in observations when the sun-synchronous satellites are absent. Such observations are seen in the 4th, 6th, 8th, 9th, 18th, 20th and 22nd hour bin. In this case they are all made by platform 18 that is in an equatorial orbit, and hence well suited for short revisit time in the GoG region.

### 4.3 Observation figures for all ships in the GoG during one week in March 2013

The data from 22nd – 28th March 2013 are used to represent the QoS achieved at the end of the GoG campaign period, see Table 4.1 for daily averages for all ships and Figure 4.4 for the histogram plots for all ships averaged over one week.

<table>
<thead>
<tr>
<th>Date</th>
<th>Daily total</th>
<th>Daily average per ship</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$n_{\text{mes}}$</td>
<td>$n_{\text{uniq MMSI}}$</td>
</tr>
<tr>
<td>22/03/2013</td>
<td>426 413</td>
<td>2 691</td>
</tr>
<tr>
<td>23/03/2013</td>
<td>359 834</td>
<td>2 626</td>
</tr>
<tr>
<td>24/03/2013</td>
<td>393 497</td>
<td>2 636</td>
</tr>
<tr>
<td>25/03/2013</td>
<td>379 209</td>
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</tr>
<tr>
<td>26/03/2013</td>
<td>423 614</td>
<td>2 712</td>
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<tr>
<td>27/03/2013</td>
<td>396 442</td>
<td>2 702</td>
</tr>
<tr>
<td>28/03/2013</td>
<td>389 337</td>
<td>2 716</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td>395 478</td>
<td>2 683</td>
</tr>
<tr>
<td><strong>Std. dev.</strong></td>
<td>23 546</td>
<td>37</td>
</tr>
</tbody>
</table>

*Table 4.1 Daily statistics for ship detection and updates in the GoG for 22nd to 28th March 2013.*

The ‘Daily total’ shows the number of messages received from all ships and the number of ships observed (denoted $n_{\text{uniq MMSI}}$) per day for the seven days. On average 395 478 messages from 2 683 ships were received per day. The ‘Daily average per ship’ shows the average performance figures for all ships each day, calculated from the individual performance figures for each ship. Over the week the daily average number of messages received from a ship was 147.4. The average number of observations per ship was 24.3, whereas the median was 26.0 (not shown in the table). The average maximum time gap between observations was 4.4 h. The number of hour-bins in which messages were received is 14.5. The average aggregated time per day that data is more than 1 hour old

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(duration_dT>1h) is 9.5 h. When 3 hours is used as limit for ‘fresh’ (duration_dT>3h) the aggregated time data is ‘old’ is 4.9 h per day. The relatively small values of the standard deviation of the weekly average of the daily figures mean that the performance is quite stable over the week.

The histograms of the performance parameters for all ships are shown in Figure 4.4. Each histogram shows the distribution of the values of the respective performance parameters calculated for each ship, hence the number of occurrences sum up to 2 683 for each histogram. The average value shown on the right side of each plot is the weekly average, as in Table 4.1. Note that whereas the average and standard deviation are well suited to describe the variation from day to day, they are not appropriate for description of the dispersed and skewed data sets, especially those having extreme values at either end; then the median (the value in the middle of the data set, that 50% of the ships are better than) or the percentage of the total that is reached at any histogram bin are more appropriate.

The histogram distributions in Figure 4.4 show:

- Number of messages (n_mes): The distribution peaks at low number of messages; the bin’s 1-5 and 5-15 have the highest number of ships, 282 and 223. However, from 15 to 235 the distribution is nearly flat with numbers around 70 ending with a second peak for 225 – 235 messages that counts 89 occurrences of ships in this n_mes interval.
- Number of observations (n_obs): The distribution of the number of observations is different from that of the number of messages: the peak is at 29 observations that has 107 occurrences and the majority of the ships have between 20 and 40 observations.
- Maximum time gap (Delta T max): The distribution peaks at 0.5 – 1.5 h, 500 ships, closely followed by 0-0.5 h (that is: update every 30 minutes, most probably ships in harbours and sea areas covered by the terrestrial MSSIS) that has 462 occurrences; together these two are 36% of the total. Note that whereas the average is 4.4 h, the median is only 3.4 h (the median is not shown); that is 50% of the ships have no data gap larger than 3.4 h. The higher average than median can be explained by the 54 ships having a max gap of 24 h.
- Number of hours with messages: the highest number of occurrences is 424 for the 24-hour bin (most of them ships in areas covered by terrestrial MSSIS). All number of hours with data has occurred, with a local maximum at 16 h.
- Data older than 1 hour: Whereas the distribution spans all durations, it is noticeable is that 460 ships, which is 17%, are in the 0th bin. The average is 9.5 h, and the median is 8.6 h, which is not so different. A local maximum of 191 ships is found at 7 h.
- Data older than 3 hours: again the distribution spans all durations, but a significant peak of 1 316 ships, which is 49%, occurs in the 0th bin. The average is 4.9 hour, partially due to the 55 occurrences, or 2%, of 21 h. whereas the median is as low as 1.3 h.

As illustrated in Chapter 4.2, the observations and gaps are dependent on the satellite orbits. Most satellite passes are in the periods 20:00-04:00 UTC and 08:00-16:00 UTC. The main cause of temporal gaps is in fact that only one or two satellites passes over in the periods 04:00-08:00 UTC and 16:00-20:00 UTC. Part of the gaps is that the analysis includes ships using class B as well as class A equipment, as well as ships entering or leaving the campaign area. Also, the results include all ships, both those ‘at anchor’ (reporting only every 3 min) and those ‘under way’. Gap in data for ships ‘at anchor’ may not be a problem is some applications. Once a ship changes it navigational status to ‘under way’, and thereby its reporting rate, the detection probability will increase.
Figure 4.4  Histograms of observation and update from all AIS data in the GoG in the period 22nd to 28th March 2013.
### 4.4 Observation figures for all ships in the HoA during one week in January 2012

The data from 16th to 22nd January 2012 are used to represent the QoS achieved at the end of the HoA campaign, see Table 4.2 for averages over the week (only weekly average shown) and Figure 4.5 for histogram plots of daily averages per ship. The results differ significantly from the results in the GoG in March 2013.

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<th>Date</th>
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</thead>
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<td>n_mes</td>
<td>n_uniq</td>
</tr>
<tr>
<td>Average</td>
<td>97 853</td>
<td>1 313</td>
</tr>
<tr>
<td>Std. dev.</td>
<td>5 060</td>
<td>9</td>
</tr>
</tbody>
</table>

Table 4.2 Daily statistics for ship detection and updates for the HoA 16th to 22nd January 2012.

Again the ‘Daily total’ shows the number of messages received from all ships and the number of ships observed per day for the 7 days. On average 97 853 messages from 1 313 ships were received per day.

The ‘Daily average per ship’ shows that over the week the daily average number of messages received per ship was 74.5. The average number of observations per ship is 14.3. The average maximum time gap between observations was 6.0 h, but the median was only 4.1 h. The number of hour-bins in which messages were received was 9.3. With 1 hour as limit for ‘fresh’ data (duration_dT>1h) the aggregated time data was ‘old’ is 14.6 h. With 3 as limit for ‘fresh’ the aggregated time data was ‘old’ was 8.6 h per day. Again the variation from day to day was small.

The histogram distributions in Figure 4.5 show:

- Number of messages (n_mes): The distribution peaks at low number of messages; the bin’s 1-5 and 5-15 have the highest number of ships, 356 and 203, and the number of occurrences is rapidly decreasing.
- Number of observations (n_obs): The distribution of the number of observations in this campaign is not so different from that of the number of messages: the peak is at 1 observation that has 112 occurrences, the majority of ships had below 20 observations, but up to 40 observations occurred.
- Maximum time gap (Delta T max): The distribution peaks at 2.5 – 3.5 h, 218 ships, closely followed by the neighbouring bin’s. The value 0-0.5 h has 61 occurrences and 0.5 – 1.5 h has 172; together these two are 15% of the total, which is significantly less than in the GoG, mostly due to smaller coverage of MSSIS. 87 ships have a max gap of 24 h.
- Number of hours with messages: the highest number of occurrences is 119 for the 1-hour bin, which is on the opposite end of the scale compared to the result from the GoG. All number of hours with data has occurred, and there is a local maximum at 16 h.
- Data older than 1 hour: Values from 5 h to 23 h have almost the same number of occurrences, and no ship has a value less than 3 h. The result is again almost the opposite of the one in the GoG, but with a local maximum at 6 -7 h.
- Data older than 3 hours: The distribution spans all durations, but a significant peak of 273 ships, which is 21%, occurs in the 0th bin. The average is 8.6 hour, but the median is 6.9 h, partially due to the 95 occurrences, or 7%, of 21-hour bin.
Figure 4.5  Histograms of observation and update from all AIS data in the HoA in the period 16th to 22nd January 2012.
4.5 QoS in the PMAR-GoG campaign compared to the PMAR-HoA campaign

Table 4.3 shows the summary of the statistics for the detailed analysis at the end of the PMAR-HoA campaign (16\textsuperscript{th} to 22\textsuperscript{nd} January 2012) and the PMAR-GoG campaign (22\textsuperscript{nd} to 28\textsuperscript{th} March 2013). When comparing the results it should be taken into account that the differences are both in time (and hence capabilities of the providers) and space (hence signal environment, both the use of the AIS channels and the interference from other sources). The two campaign areas are however at approximately the same latitude and of the same size; hence the number of satellite passes is comparable. Note that the coverage of the terrestrial stations is more extensive in the GoG- than in the HoA campaign.

<table>
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<tr>
<th>Date</th>
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</thead>
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<tr>
<td></td>
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<td>PMAR-HoA</td>
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<td>14.3</td>
<td>6.0</td>
<td>9.3</td>
</tr>
<tr>
<td>PMAR-GoG</td>
<td>395 478</td>
<td>2 683</td>
<td>147.4</td>
<td>24.3</td>
<td>4.4</td>
<td>14.5</td>
</tr>
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</table>

Table 4.3 Daily statistics for ship detection and updates in in the PMAR-HoA campaign for the period 16\textsuperscript{th} to 22\textsuperscript{nd} January 2012 and the PMAR-GoG campaign for the period 22\textsuperscript{nd} to 28\textsuperscript{th} March 2013.

The number of observations per ship per day has increased by 10; from 14.3 in the PMAR-HoA to 24.3 in the PMAR-GoG. Comparing the second histogram in Figure 4.4 and Figure 4.5 shows that the number of occurrences of low number of observations is somewhat decreased from the PMAR-HoA to the PMAR-GoG, whereas the number of occurrences of 20 – 40 observations has increased significantly.

The average maximum time gap has been reduced by 1.6 h, from 6.0 h to 4.4 h. The reduction by 1.6 h makes a 25% reduction of the average gap time.

Considering the figures for ‘old’ data, both the 1-hour and the 3-hour figure is improved significantly. Two features are visible in the histograms from the PMAR-GoG campaign; the occurrence of a significant percentage of ships in the 0\textsuperscript{th} bin, which mainly can be attributed to ships within the coverage of terrestrial stations; elimination of the occurrences at extremely high values, as well as a general shift towards lower value, which can be attributed both to the observations made by terrestrial stations and better performance of the SAT-AIS systems.

Using the 3-hour figure as example, the average is reduced from 8.6 to 4.9 h. The number of ships in the 0\textsuperscript{th} bin (that is, an aggregated value 0 – 0.5 h that can be interpreted as fulfilling the requirement for update every 3 hours) has increased from 270 (21\%) in the PMAR-HoA to 1 316 (49\%) in the PMAR-GoG campaign.

5 Quality of service vs. number of providers

This chapter presents the sensitivity of how well the ships can be tracked vs. the number of data providers. Data from the GoG in the period from 22\textsuperscript{nd} to 28\textsuperscript{th} March 2013 is used. The analysis is similar to the one in the previous chapter, but the performance figures are calculated for increasing numbers of providers.
5.1 Number of observations and temporal performance

Table 5.1 shows the performance figures vs. number of providers, Figure 5.1 shows graphs of the number of observations as well as the temporal performance from the ‘Daily average per ship’.

<table>
<thead>
<tr>
<th># of prov's</th>
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<th>Daily average per ship</th>
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<td></td>
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<td>w mes</td>
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</tr>
<tr>
<td>--------</td>
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<tr>
<td>1</td>
<td>38 273</td>
<td>2 175</td>
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<tr>
<td>2</td>
<td>225 054</td>
<td>2 559</td>
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<tr>
<td>3</td>
<td>246 233</td>
<td>2 590</td>
</tr>
<tr>
<td>4</td>
<td>395 478</td>
<td>2 683</td>
</tr>
</tbody>
</table>

Table 5.1 Statistics for ship detection and updates in the PMAR-GoG campaign vs. number of data providers, figures are averaged for the period 22\textsuperscript{nd} to 28\textsuperscript{th} March 2013.

The ‘Daily total’ shows that 2 175, 2 559, 2 590 and 2 683 ships are detected per day by one, two, three and four providers, respectively. The addition is 384 ships when increasing from one to two SAT-AIS providers, 31 for the third SAT-AIS provider, and 93 for when introducing the terrestrial network in the last step (four providers). That is, the increase in number of ships detected is small at high number of providers, simply because the number of ships detected is getting close to the total number of ships using AIS.

Figure 5.1 Daily averages per ship; temporal performance vs. number of providers. Data from 22\textsuperscript{nd} – 28\textsuperscript{th} March 2013.
The ‘Daily average per ship’ shows however that the number of observations increases steadily, the trend is practically linear: each new provider contributes approximately 7 observations. The trend for $dT_{\text{max}}$ is almost linear, the gap is reduced by 1.9 h, 2.8 h, and 1.9 h for each provider added, from 10.9 h for one provider to 4.4 h for four providers. For $duration_{dT} > 1h$ the gaps are decreasing a little more rapidly than the $dT_{\text{max}}$, 3.1 h, 3.9 h, and 3.7 h. For $duration_{dT} > 3h$ the third provider contributes somewhat better than the second and the fourth, the decrease in the different steps being 3.7 h, 5.7 h and 2.0 h.

### 5.2 Ship positions

Figure 5.2 shows a sequence of maps of ship positions for increasing number of providers. Data from 25\textsuperscript{th} March 2013 are used. With only one provider, 2 180 ships are detected. The ships are in the entire PMAR-GoG area, and traffic lanes and harbours are visible. When data from more providers are added the trajectories of individual ships become more prominent. It is also evident that some erroneous reports are received; some ships appear on the African continent (such ship positions are not used when building the MSP).

![Figure 5.2 Maps of reported ship positions for all ships during one day as data are added; data from one, two, three and four data providers on 25\textsuperscript{th} March 2013.](image)
The plots in Figure 5.3 show only the positions of those ships that are added to the picture when the number of providers is increased on 25\textsuperscript{th} March 2013. When going from one to two SAT-AIS providers the increase is 389 ships. The reports are scattered over the PMAR-GoG area, but new ships occur somewhat more often in coastal areas than at seas; the occurrence is fairly uniform and proportional to the ship density. When the third SAT-AIS provider is added 39 more ships are observed. The reports are now mainly coming from coastal areas and ports. Sometimes new ships also occur near the perimeter of the area; ships leaving or entering may be present only for a short time, and therefore only detected by one provider. For the positions of ships only observed by the fourth provider, the terrestrial MSSIS stations, two plots are shown, (a) and (b), the second one from March 28\textsuperscript{th}; both show that the additions are in ports and in coastal areas around the Canary Islands and Cap Verde.

Concerning erroneous positions reports, the plot for 28\textsuperscript{th} March shows three examples at sea. They are seen near the equator, approximately 500 km from the coast, outside the maximum possible range of the terrestrial stations. In the ship tracking, such anomalies are usually detected and the reports are not used when building the MSP.

**Figure 5.3** Maps of reported ship positions from the ships added by the second, third and fourth provider only, on 25\textsuperscript{th} March 2013, as well as 28\textsuperscript{th} March for the fourth provider (b).
The number of messages per day for the added ships is relatively low when adding SAT-AIS providers; on average 2 and 7 messages per ship for the two increments shown, hence it is evident that these ships are more difficult to detect than the average ship. For the ships added by the terrestrial stations, the average number of messages is somewhat different; more than 80 messages per day per ship. We can still assume that it is ships that are difficult to detect by satellite; some because they use class B equipment, others because they have poor AIS installations. However, the shorter distance between ship and terrestrial stations, as well as the continuously monitoring, makes detection by terrestrial stations possible up till approximately 50km from the coast.

5.3 Summary of performance vs. number of providers
Analysis of data from 22nd to 28th March 2013, which is at the end of the PMAR-GoG campaign period, shows that the number of ships observed \((n_{uniq\_MMSI})\) increases from 2 175 for one provider to 2 683 for four providers; the increase is 384 and 31 ships respectively for the second and third SAT-AIS provider and 93 ships for MSSIS added as the fourth provider.

The temporal performance trends show that all providers contribute significantly; the average maximum time gap \((dT_{max})\) decreases from 10.9 h to 4.4 h in steps of 1.9 h, 2.8 h, and 1.9 h, or on average 2.2 h per provider.

The contribution of MSSIS in the PMAR-GoG is significantly higher than in the PMAR-HoA. In the PMAR-GoG the terrestrial network contributes on a similar level as the SAT-AIS provider, and in fact gives continuous tracking along parts of the African continent as well as the Canary Islands and Cap Verde.

6 Summary and conclusion
The two PMAR campaigns have shown that AIS is a viable, current and effective tool to assist in vessel tracking on regional level. In this paper, the methods for calculation of the quality of service (QoS) for the Maritime Situational Picture (MSP) based on the detection performance figures for each ship have been shown. In the first campaign, off the Horn of Africa, 1st August 2011 – 31st January 2012, typically 1 300 ships were tracked with an average \(dT_{max}\) (maximum time gap between consecutive messages from one ship received by any platform) of 6.0 h. In the second campaign, in the Gulf of Guinea, 1st October 2012 – 31st March 2013, typically 2700 ships were tracked with a \(dT_{max}\) of 4.4 h.

When comparing the QoS of the two “Piracy, Maritime Awareness and Risks” (PMAR) campaigns, it should be kept in mind that even though the areas are at approximately the same latitude (hence the number of satellite passes is comparable), the platforms (the capabilities of the providers) are different and the geographic areas (the ship traffic and the signal environment of the AIS channels including interference from other sources) are different.

Given these differences, it has been shown that the number of observations (as defined in section 4.1) per ship per day has been increased by 10; from 14.3 in the PMAR-HoA to 24.3 in the PMAR-GoG. Considering the temporal performance, the average \(dT_{max}\) has been reduced by 1.6 h, which is a 25% reduction of the gap. Considering the 3-hour figure for ‘fresh’ data, the number of ships in the 0th
bin (that can be interpreted as fulfilling the requirement for update every 3 hours) has increased from 270 (21%) in the PMAR-HoA to 1 316 (49%) in the PMAR-GoG.

Whereas the number of satellites used in the GoG- as well as in the HoA campaign was seven to eight, they were not all the same; one new advanced satellite was launched at the start of the GoG campaign, whereas one old standard satellite was out of service at the end. Further, the coverage of the terrestrial stations was more extensive in the GoG- than in the HoA campaign, with coverage of major ports as well as piecewise coastal coverage and coverage of the seas around the Canary Islands and Cape Verde in the GoG campaign.

The analysis of the sensitivity of the QoS to the number of data providers shows that the number of ships observed per day increases less for the third SAT-AIS provider added than for the second. It is reasonable that the number of ships added in a time period as long as a day is small as the number of ships detected comes close to the actual number of AIS-carrying ships in the area. It is however seen that on average the number of messages per ship for the added ships was much lower than for the average ship, hence it is evident that the ships added by the last provider are more difficult to detect than the average ship.

The temporal performance increases almost linearly with the number of providers used; in the GoG campaign all SAT-AIS providers make a significant contribution to the ship updates and the ‘freshness’ of the picture, as does the terrestrial network; the average maximum time gap was reduced from 10.9 h to 4.4 h in steps of 1.9 h, 2.7 h and 1.9 h when adding the second, third and fourth provider, respectively.

Note that the performance calculations include ships using AIS class B- as well as class A equipment. Also, the data comprise ships that enter or leave the area during the day, and hence give rise to an increase of the average gap time. The results are for all ships, both those ‘at anchor’ (reporting only every 3 min) and those ‘under way’; some applications may not require update of ships at anchor.

The main cause of temporal gaps, however, is in fact that only one (some days two) of the eight satellites passes over the area of interest in the periods 04:00-08:00 UTC and 16:00-20:00 UTC, whereas the number is up to eight for the periods 08:00-16:00 and 20:00-04:00 UTC.

The third PMAR campaign starting in 2014 will provide a live Maritime Situational Picture during one year to maritime operations centres in East Africa as part of the “Regional Maritime Capacity Building”. This will also give the possibility of following the development of the QoS of the cooperative MSP built from AIS data.

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References


