TABLE 10

Examples of D/U calculations for a typical environmental ground station in central United States to the satellite communicating with a ship in the Atlantic Ocean

Co-channel system to Satellite			Ship to Satellite			
Azimuth (deg)	**Elevation (deg)**	**Range (km)**	**Azimuth (deg)**	**Elevation (deg)**	**Range (km)**	**D/U (dB)**
			Pass 1			
9.1	24.8	1 838.9	316.7	1.5	3 470.7	**–11.5**
16.1	33.6	1 534.4	310.3	3.4	3 274.1	**–12.6**
28.7	44.6	1 285.6	303.1	5.0	3 115.5	**–13.7**
54.4	55.4	1 131.2	295.3	6.2	3 001.5	**–14.5**
95.4	57.0	1 112.1	286.9	6.9	2 937.7	**–14.4**
125.8	47.4	1 234.7	278.2	7.0	2 927.4	**–13.5**
140.9	35.9	1 463.6	269.7	6.5	2 971.0	**–12.1**
149.0	26.5	1 757.3	261.6	5.4	3 066.1	**–10.8**
153.8	19.1	2 087.8	254.1	3.9	3 207.5	**–9.7**
157.1	13.2	2 439.3	247.4	2.1	3 388.9	**–8.9**
159.4	8.3	2 803.1	241.4	0.1	3 603.5	**–8.2**
112.6	3.1	3 290.4	217.1	28.2	1 693.2	**–0.2**
117.9	0.5	3 556.0	208.7	21.1	1 982.8	**–0.9**
			Pass 2			
93.9	0.5	3 568.8	184.1	65.3	1 038.1	**4.7**
87.0	1.5	3 464.2	63.6	89.3	956.9	**5.2**
79.8	2.1	3 401.9	7.3	64.9	1 043.2	**4.3**
72.4	2.3	3 384.5	6.7	45.9	1 262.7	**2.6**
65.0	2.0	3 413.0	6.6	32.7	1 559.6	**0.8**
57.8	1.4	3 486.3	6.7	23.3	1 897.0	**–0.7**
51.1	0.3	3 601.3	6.8	16.4	2 255.9	**–1.9**
52.6	1.5	3 477.2	3.9	18.4	2 142.9	**–1.8**
59.9	1.3	3 487.0	7.7	25.6	1 802.5	**–0.3**
67.0	0.9	3 536.0	13.9	35.0	1 493.1	**1.5**
73.8	0.1	3 622.7	25.7	47.3	1 239.7	**3.3**
144.3	4.7	3 122.4	230.7	5.0	3 098.7	**–5.9**
147.3	1.2	3 472.4	225.4	2.1	3 376.8	**–5.8**
38.5	1.1	3 514.7	358.1	8.2	2 841.9	**–4.2**
94.2	1.5	3 457.1	201.5	65.5	1 036.2	**4.5**
150.9	20.4	2 021.3	255.4	4.9	3 115.2	**–9.8**
154.7	14.3	2 366.4	248.4	3.1	3 288.7	**–8.9**
157.4	9.3	2 725.9	242.2	1.0	3 497.6	**–8.2**
102.9	13.2	2 445.7	261.2	30.3	1 627.0	**–2.5**
92.5	14.8	2 347.1	279.3	32.7	1 554.9	**–2.4**
81.3	15.3	2 315.9	298.2	31.7	1 584.9	**–2.7**
70.3	14.7	2 354.9	314.5	28.0	1 711.4	**–3.2**
59.9	13.1	2 460.7	326.9	22.9	1 914.9	**–3.8**
50.9	10.9	2 625.1	336.0	17.8	2 173.2	**–4.4**
43.2	8.2	2 837.4	342.7	13.1	2 468.1	**–4.8**

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Fortunately, most mobile communications systems operate at less than a 100% transmit duty cycle. Based on over-the-air spectrum measurements performed in the United States in selected portions of the 138-174 MHz band and other data sources, it is possible to broadly categorize mobile service transmitters into high (30-100%), medium (10-30%), and low (<10%) duty cycle categories. Examples for each category are given in Table 11.

TABLE 11

Example Mobile System Transmit Duty Cycle

High duty cycle (30-100%)	**Medium duty cycle (10-30%)**	**Low duty cycle (<10%)**
Paging Systems	Multiple User LMR Business/Industrial Repeaters (i.e. Community Repeaters)	Most Single-User Private LMR Systems
Trunking System Control Channel	Public Safety Dispatch	Most Administrative Government LMR Systems
Broadcast Type Systems (such as weather broadcasts)	Trunking System Communication Channels	Some Types of LMR Fixed Control Links
Some Transportable Telemetry (such as seismic sensors)	VHF Maritime Mobile Working Channels	
VHF Public Correspondence Coast Stations		
Some Types of LMR Fixed Control Links		

Analysis of the co-channel operation of VPCS and LMR transmitters having a transmit duty cycle less than 100% can be accomplished in a similar manner as the intra-system performance analysis described earlier. As in the intra-system analysis, the key technical parameters to consider are the transmitter EIRP, the antenna elevation gain pattern, and the transmitter duty cycle. Analysis of the co-channel impact from VPCS/LMR transmitters can be accomplished by simply adding the additional transmitters into the simulation model described earlier using the appropriate EIRP, antenna, and duty cycle parameters. For this study, a mobile system was used having an EIRP of 50 dBm, vertical polarization and a cosine squared antenna elevation pattern. AIS parameters described in Table 5 were used. The only change necessary was to account for the fact that most mobile systems operate on a single frequency rather than the alternating frequencies of AIS transmitters.

Figures 24 through 27 present the results under a variety of conditions for the baseline single satellite/single overpass scenario. Figure 24 shows the percent of ships detected if there were 1 000 Class A ships in the satellite footprint and both AIS channels were used with co-channel mobile systems having a range of transmit duty cycles. Figure 25 is the same except that only one channel, AIS 1 or AIS 2, were used with co-channel mobile systems. Figure 26 is a third example where the duty cycles of the co-channel mobile systems are unevenly distributed on AIS 1 and AIS 2. Figure 27 is an example where the satellite is effectively operating at capacity with 1 415 ships in the mainbeam (i.e. 80% of the ships are detected) and co-channel mobile systems are sharing on only one AIS channel. Figure 28 is similar to Fig. 27 except using the 6 satellite/12 hour observation scenario. Table 12 summarizes the criteria used to develop Figs. 24 through 27.

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TABLE 12

Summary of Criteria Used to Develop Figs. 24 through 28

Figure	No. of Satellites	Observation Period	No. of Ships within Footprint	Mobile Duty Cycle on AIS 1	Mobile Duty Cycle on AIS 2
24	1	Single Overpass	1 000	Varies*	Varies
25	1	Single Overpass	1 000	Varies	No mobiles
26	1	Single Overpass	1 000	Varies	All 10%
27	1	Single Overpass	1 415**	Varies	No mobiles
28	6	12 Hours	2 381**	Varies	No mobiles

* Varies = All co-channel mobile systems within satellite footprint have a duty cycle as indicated on each figure.

** Satellite is at capacity (defined as detecting 80% of the ships) for the given scenario.

FIGURE 24

Satellite Detection Performance Statistics with Co-Channel Mobile System (Equal Co-Channel Operation on Each AIS Channel)

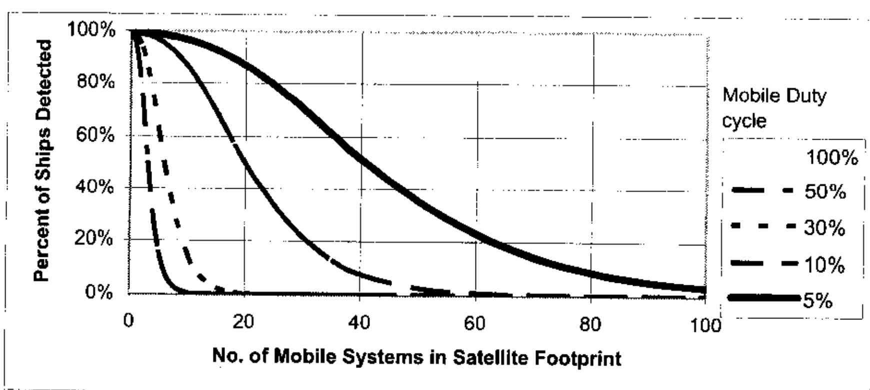


FIGURE 25

Satellite Detection Statistics with Co-Channel Mobile Operation
(Co-channel Operation on One AIS Channel Only)

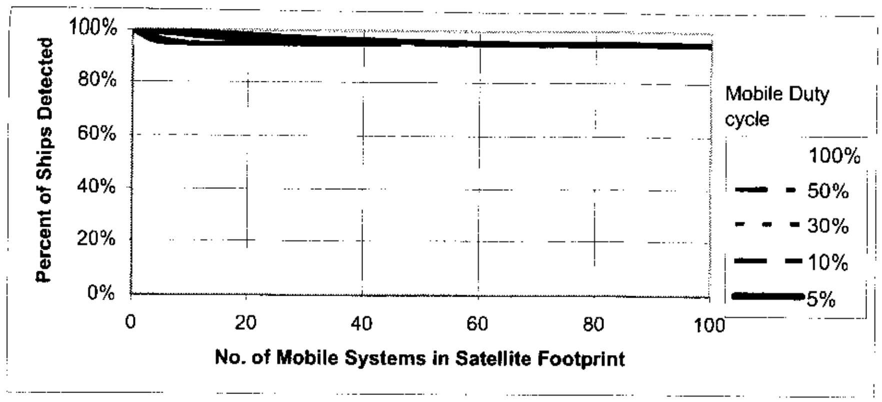


FIGURE 26

Satellite Detection Performance with Co-Channel Mobile Operation
(Duty Cycle at 10% on One Channel Only)

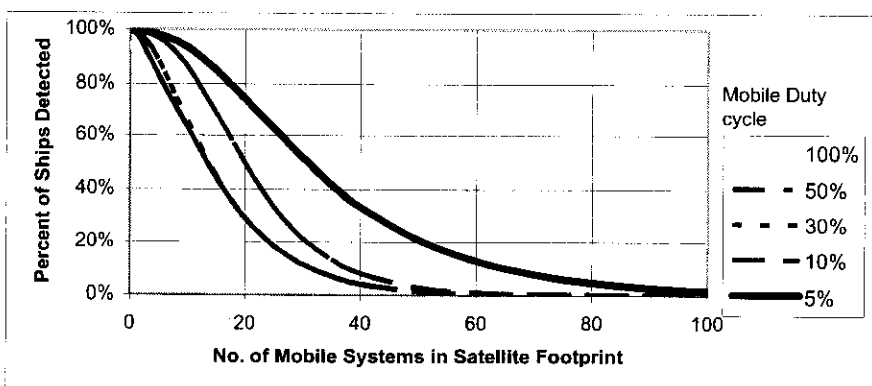


FIGURE 27

Satellite Detection Performance with Co-Channel Mobile Operation
(Satellite Operating at Capacity (80% Detection); Co-channel operation on One AIS channel)

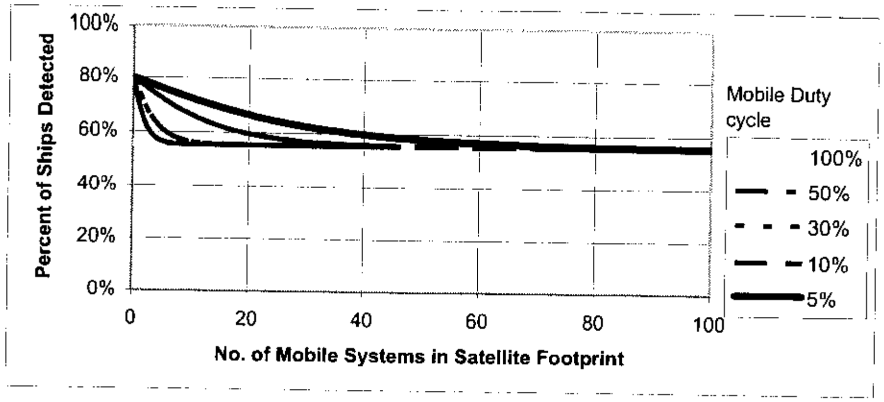
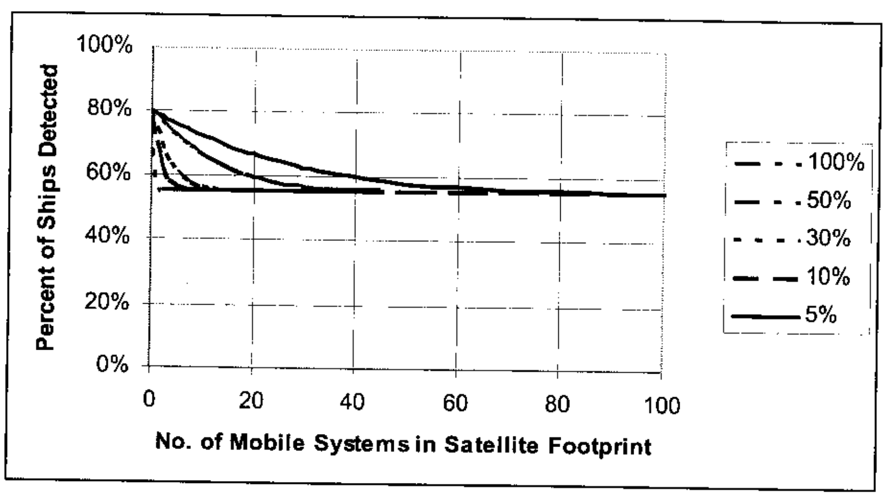


FIGURE 28

Satellite Detection Performance with Co-Channel Mobile Operation
(Satellite Operating at Capacity (80% Detection);
Co-channel Operation on One AIS Channel Only; Six Satellite Scenario)



The examples shown in the figures above illustrate AIS satellite detection performance under a variety of assumptions. Because of the multidimensional nature of these curves it was not practical to address all possible conditions. In some administrations, the sharing situation is different for the two frequencies used by AIS. In such situations, Figs. 27 and 28 provide the limiting case where sharing is present on one AIS channel and AIS is operated on an exclusive basis on the other channel. For both the single satellite and six satellite scenarios, these two figures show that a limited number of low duty cycle, co-channel mobile systems within the satellite footprint have a minimal effect of AIS satellite detection performance. For the case of larger numbers of co-channel mobile systems within the satellite footprint, satellite detection of AIS is still possible albeit with a lower, percentage of the ships detected.

Adjacent Channel Mobile Compatibility

As with all mobile communications systems, sharing with adjacent channel systems is also a factor to be considered. It is recognized that satellite operations must take into account existing adjacent channel systems that operate in accordance with existing out-of-band emission requirements.

For the present study, two scenarios need to be addressed:

Case 1. compatibility considering AIS transmitters and adjacent channel mobile system receivers, and

Case 2. compatibility considering adjacent channel mobile system transmitters and the satellite receiver.

The first case is, of course, not a new situation and exists irrespective of satellite AIS detection. This has been examined and documented in a detailed measurement and analysis report on public record in the United States.[8] The study considered a worse-case AIS signal (2-second transmit interval) and mobile system receivers having both analog frequency modulation (FM) voice and digital data operating modes. In the FM voice mode, the study concluded that when separated in frequency by 25 kHz and with antennas as close as 3 metres, performance degradation was minimal and would not prevent normal using of the mobile system. The study further concluded that use of forward error correction would be necessary in the mobile system receiver when operating in the digital data mode to assure compatible operation. These results would be applicable to any adjacent channel pair on any frequency in the 156-162.025 MHz maritime mobile band.

The second case is unique to satellite AIS detection. Just as in the case of co-channel operation, other mobile systems will also be operating on channels adjacent to those used by AIS. The three channels adjacent to AIS 1 and AIS 2 are 161.950, 162.000 and 162.050 MHz. Addressing adjacent channel considerations introduces additional dimensions to the study, namely the distribution of mobile systems across the five channels and the degree of adjacent channel rejection possible in the satellite receiver. The primary focus of this adjacent channel examination is to isolate the specific effects on AIS satellite detection of mobile systems operating on the adjacent channels.

Adjacent Channel Rejection. To meet applicable IEC specifications, conventional shipboard AIS receivers are required to have at least 70 dB of adjacent channel rejection. However, a satellite AIS receiver must be optimized for maximum sensitivity and may not be able to achieve this level of adjacent channel performance. For purposes of this study, adjacent channel rejection values of 30 dB, 40 dB and 50 dB are considered.

Distribution of Mobile Systems. Since various administrations may use the five channels considered herein in a variety of ways with respect to mobile systems, the number of mobile systems operating on each of the channels may vary widely in various geographic regions. However, it was beyond the scope of this study to examine differing mobile system usage on the three adjacent channels. For purposes of this study, the number of mobile systems operating on the channels adjacent to AIS located within the satellite antenna footprint was assumed to be the same on all three channels.

Geographic Distribution of AIS-equipped Ships. Because of the multidimensional nature of the issues being addressed, the cases addressed below considered only a single density of ships, specifically 1 000 Class A AIS-equipped ships uniformly distributed within the satellite footprint.

[8] Roberts, Melvin S., et al, EMC Analysis of Universal Automatic Identification and Public Correspondence Systems in the VHF Maritime Band, Joint Spectrum Center, Annapolis Maryland, February 2004

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Results. Using the simulation model described earlier, the effect on the performance of AIS satellite detection as a result of adjacent channel mobile systems was examined. The analysis methodology used was to reduce the transmit power of the adjacent channel mobile systems by an amount equal to the indicated adjacent channel rejection at the satellite receiver, dB for dB. Table 13 lists the analysis results showing the percent of ships detected as a function of various parameters. In this table, the maximum number studied of mobile transmitters on each adjacent channel was 240 and the maximum transmit duty cycle used was 30%.

TABLE 13

Results of Adjacent Channel Study*

No. of Ships	No. of Mobiles on AIS 1 and 2	No. of Adjacent Channel Mobiles**	Mobile Duty Cycle	Adjacent Channel Rejection	Percent of Ships Detected
1 000	0	0	–	–	100%
1 000	0	40	5%	30 dB	100%
1 000	0	80	5%	30 dB	97%
1 000	0	160	5%	30 dB	70%
1 000	0	240	5 %	30 dB	15%
1 000	0	20	10%	30 dB	100%
1 000	0	40	10%	30 dB	90%
1 000	0	80	10%	30 dB	60%
1 000	0	160	10%	30 dB	0%
1 000	0	TBD	30%	30 dB	TBD
1 000	0	TBD	30%	30 dB	TBD
1 000	0	240	5%	40 dB	100%
1 000	0	240	10%	40 dB	100%
1 000	0	160	30%	40 dB	100%
1 000	0	240	30%	40 dB	80%
1 000	0	240	30%	50 dB	100%

* All cases examined assumed a uniform geographic distribution of AIS-equipped ships and mobile systems located within the satellite antenna footprint.

** Number of mobiles on each of the three channels adjacent to AIS 1 and AIS 2.

As expected, the analysis results show that the performance of AIS satellite detection in the presence of coexisting adjacent channel mobile systems is strongly dependent on the amount of adjacent channel rejection available in the satellite receiver and the transmit duty cycle of the mobile systems. The analysis shows that with only 30 dB of adjacent channel rejection, the performance of AIS satellite detection can be degraded with only a moderate number of coexisting adjacent channel mobile systems. With 40 dB of adjacent channel rejection, AIS satellite detection becomes much more robust with coexisting adjacent channel mobile systems. With 50 dB of adjacent channel rejection, no reduction of detection performance was identified within the range of parameters studied.

10 Summary

This contribution introduces the concept of satellite detection of AIS messages for the current terrestrial AIS system, and demonstrates, under a given set of assumptions, the technical feasibility and capacity of AIS satellite receivers to operate in an environment of a large number of AIS-equipped ships. Five scenarios were included which defined the number of AIS-equipped satellites (1 and 6 satellites) and the period of time allowed for updating ship locations (single satellite overpass to 12 hours). Satellite capacity (defined at detecting 80% of the ships) ranged from 1 415 to 2 380 for these scenarios. Analyses conducted using a representative worldwide distribution of AIS-equipped ships showed that ship densities in many regions of the world are expected to exceed these calculated AIS capacity limits.

Four candidate techniques were investigated to enhance satellite capacity, which individually showed capacity improvements of up to 175%.

The study investigated co-channel operation between the two AIS designated channels with other mobile communications systems. Because of the large satellite antenna footprint, mobile systems operated several thousand kilometres from navigable waterways can affect the performance of AIS satellite detection. Results showed that AIS satellite detection can co-exist with a limited number of low-duty-cycle, co-channel mobile systems. The results further showed that AIS satellite detection is much more robust when co-channel sharing with mobile systems was present on only one of the channels used by AIS.

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