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PERFORMANCE ASSESSMENT AND INTEROPERABILITY OF PROPOSED CLASS B AIS WITH EXISTING CLASS A AIS SYSTEM USING SIMULATION SOFTWARE

1 Introduction

The operation of Automatic Identification System (AIS) technology is governed by logic rules built into each device. The rules for Class A AIS equipment are now established as published in ITU-R M.1371-1 Recommendation with minor adjustments published in the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) Technical Clarifications on ITU Recommendation ITU-R M.1371-1, edition 1.4. The complexity of these rules makes it difficult to analyze AIS performance as the local number of AIS units grows to many hundreds or thousands. Since physical tests under such conditions were considered prohibitively expensive, the U. S. Coast Guard Research and Development Center (R&DC) developed computer simulation software for assessing the effectiveness of AIS equipment interaction.

As development of Class B AIS technology progressed, a number of additional methods and rules were proposed for Class B devices. These proposals were primarily intended to ensure that Class B equipment would have a minimal impact on the level of operational performance that is expected by Class A equipment users – the mariners for whom the International Maritime Organization (IMO) defined AIS technology. Working Group 8a (WG 8A) of the International Electrotechnical Commission (IEC) Technical Committee (TC) 80 desired to recommend a Class B that provided acceptable performance, and more importantly, closely supported the spirit of IMO Resolution MSC.140(76) – “Recommendation for the Protection of the AIS VHF Data Link.”

The alternative Class B rules proposed by IEC WG 8A were added to the R&DC computer simulation. The simulation was then configured using two separate geographic vessel traffic patterns, and the relative performance of the alternative methods and rules compared. The objective of this paper is to report the findings that support the IEC decision to recommend the introduction of Class B technology that uses the Carrier Sense TDMA (CSTDMA) access scheme.

The computer simulation is designed to create a “virtual” environment where "virtual AIS units" are put in motion and interact. The operation of each AIS unit follows the rules for a particular type of AIS device – Class A, Class B (SOTDMA), Class B (CSTDMA), etc. These rules are described in documents, such as, ITU-R M.1371-1, IALA Technical Clarifications on ITU Recommendation ITU-R M.1371-1, new rules proposed by IEC WG 8A, or by the laws of physics for radio design and signal propagation. A major factor in the simulation’s results is the modeled signal propagation loss between each virtual AIS unit.

The relative movement and location of units during the simulation determines the signals received from the other units in the simulation. Rather than attempting to simulate the motion of each unit in the simulation, the simulation uses actual vessel movement reports captured from different geographic areas using the R&D Center's AIS research network.

The simulator package also includes display software that provides tabular and geographic windows by which the interactions of the simulation's virtual AIS units can be viewed.

2 Objective

The simulation scenarios were designed to assess the relative performance of alternative Class B methods and rules. The measure of performance is the ratio of successfully received AIS messages to "receivable" AIS messages, expressed as a percentage. A "receivable" message signal level is sufficient for reception, but it may not be received due to interference from another signal. The simulation results distinguish this performance measure by the type of receiver (Class A or Class B) and the type of transmitter (Class A or Class B).

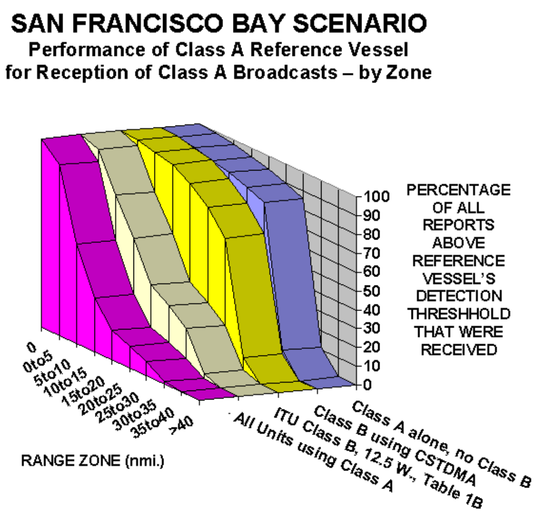
3 Presentation of Simulation Results

The simulation's results are presented in both graphical and tabular form. The information is the same in both forms. The following graph and table show the reception performance from a Class A perspective for several "San Francisco Bay" simulation scenarios. Additional figures with results are provided in section 5.

R&DC prepared and used two separate simulation scenarios. The "San Francisco Bay" scenario used vessel movement data recorded from the San Francisco Bay area. This scenario contained 1 reference unit, 149 Class A units, and 700 Class B units. The second, "Florida," simulation scenario used vessel movement data recorded from 2 255 vessels off of the Miami, Florida coastline – 1 reference unit, 350 Class A units and 1904 Class B units.

FIGURE 1

Performance Summary for San Francisco Bay scenario, Class A reception of Class A units - example of graphic and tabular simulation results.



Percentage of possible Class A receptions that were correctly received aboard reference Class A vessel during indicated simulation scenarios.				
Distance from reference vessel (nm.)	150 Class A + 700 Class A on non-SOLAS vessels	150 Class A + 700 Class B (1371-1 12 Watt)	150 Class A + 700 Class B (CSTDMA 1 Watt)	150 Class A alone
0 – 5	90.6	96.3	99.3	99.4
5 – 10	52.5	76.4	97.5	97.9
10-15	28.1	58.2	95.5	95.3
15-20	15.3	37.5	89.7	93.5
20-25	11.5	30.8	81.1	89.9
25-30	7.1	22.9	69.3	86.2
30-35	0.8	3.3	9.8	11.9

The results shown above are from four separate “runs” of the “San Francisco” scenario. For each of the “runs” the operating rules for the Class B units were changed while all the other simulation conditions remained constant. The primary evaluation criteria was the success that the reference Class A unit had in receiving messages broadcast by the other Class A units in the simulation. The reception results are summarized for every 5 nautical mile wide zone from the reference unit. The 0 to 5 nautical mile zone is closest to the reference unit and the 30 to 35 nautical mile zone is the furthest. The reference unit and all other units are in constant motion during the simulation. Therefore, the distance between the reference unit and all other units was constantly changing. The Class B rule sets used for the four scenarios are: (1) All “Class B” units are replaced by Class A units but use antennas 20 feet above the water (This is the current state. That is, no commercial Class B units exist.); (2) Class B units operate using the ITU-R M.1371-1 SOTDMA access scheme and 12.5 Watts; (3) Class B units operate using CSTDMA, 1 Watt, and the operating rules in the IEC 62287 CDV; and (4) Class B units do not transmit (no Class B interference, ideal Class A reception conditions).

In Figure 1, the table lists the reference Class A unit’s success in the reception of other Class A broadcasts with the results grouped into “range zones” away from the reference unit. This is shown for each of the four Class B rule sets. The right most table column, “150 Class A alone,” shows the performance for the “best” possible Class A scenario - no Class B units transmitting. The next best performance is the “150 Class A + 700 Class B (CSTDMA 1 Watt)” scenario. Compared to this “Class B (CSTDMA 1Watt)” scenario, the performance of the “150 Class A + 700 Class B (1371-1, 12 Watt)” scenario is dramatically worse; this scenario applies the SOTDMA methods and rules recommended in the current ITU-R M.1371-1 standard.

The left most column, “150 Class A + 700 Class A on non-SOLAS vessels,” shows the worst performance. In this scenario, all 850 units use the ITU-R M.1371-1 Class A methods and rules. However, 700 of the units operate with 20 foot high antennas.

Figure 1 also shows the tabular percentages in a graphical form. The graphical form allows the reader to quickly see the relative performance difference between the four scenarios. The results in Figure 1 show the most dramatic performance difference between Class B CSTDMA and Class B SOTDMA. While not as dramatic, the same basic relative performance difference can be seen in the “Florida” scenarios (See Figure 5.).

4 Simulation Scenarios

The major elements of a simulation scenario are:

– type of AIS unit (methods and rules as discussed above);

– location and motion of each AIS unit;

– installation characteristics of each AIS unit, and

– transmitted signal attenuation between any two AIS units.

The location and motion (speed and course over ground) for each AIS unit is governed by the location and motion of a recorded vessel track. The desired density of vessel tracks was constructed from multiple days of recorded vessel tracks. Figure 2 shows the 2 255 vessel tracks used in the “Florida” scenario. During the running of each scenario, the geographic relationships between all units changes and the separation distance must be continually recalculated. This zones around the reference unit move with the reference unit, and the number of units in each zone changes as the simulation progresses.

The simulation permits each AIS unit to be installed with different characteristics – transmit power levels, antenna height, receiver sensitivity, etc. Table 1 lists some of the settings used during this series of simulations. The simulation mechanics assume that all units maintain synchronization using a time source or semaphore methods. The simulation does not include bit stuffing, analysis of synchronization, or adjustments for propagation delay.

FIGURE 2

Vessel tracks used in the "Florida" scenario.

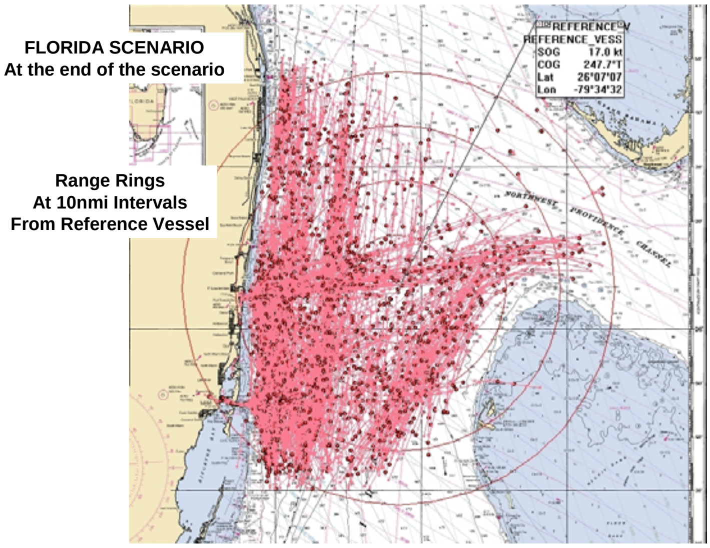


TABLE 1

Class A and Class B unit characteristics for each scenario.

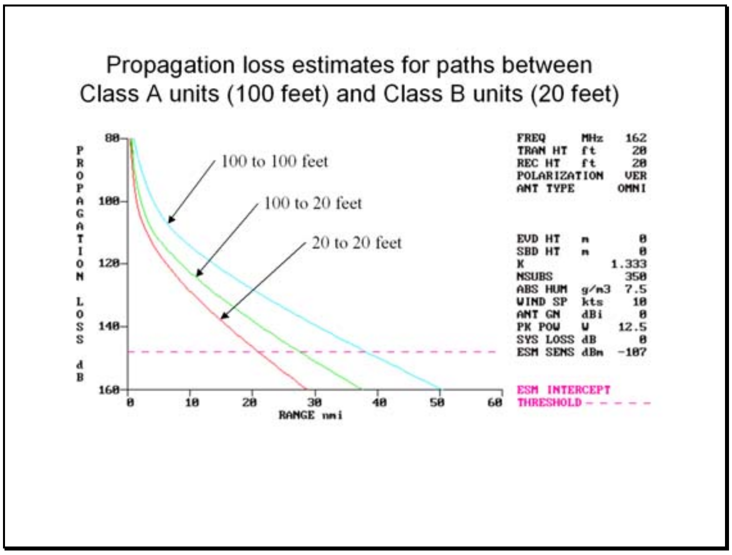
Scenario	San Francisco Bay	Florida
Total Units (including reference)	**850**	**2255**
Class A Units	**149**	**350**
Antenna Height	100 feet	100 feet
Feedline loss	4 dB	4 dB
Power level	12.5 Watt	12.5 Watt
Co-channel Rejection	10 dB	10 dB
Class B Units	**700**	**1904**
Antenna Height	20 feet	20 feet
Feedline loss	4 dB	4 dB
Power level	12.5 Watts, 1 Watt, or receive only	12.5 Watts, 1 Watt, or receive only
Co-channel Rejection	10 dB	10 dB
Receiving Sensitivity	**-107 dBm**	**-107 dBm**
Minimum Speed	**10 knots**	**0.5 knots**

The antenna height and separation distance determines the transmitted signal attenuation between any two units. The simulation accepts propagation attenuation in the form of tables. The content of these tables can be either modeled attenuation or actual measurements. Modeled attenuation was used for this series of simulations. The simulation also has a capability to vary the attenuation about the nominal table value using Rayleigh distribution statistics, however this feature was not used during this series of simulations.

The PROPR propagation-loss model developed by the Naval Command, Control, and Ocean Surveillance Center was used to develop the simulation’s attenuation tables (Shown below.)

FIGURE 3

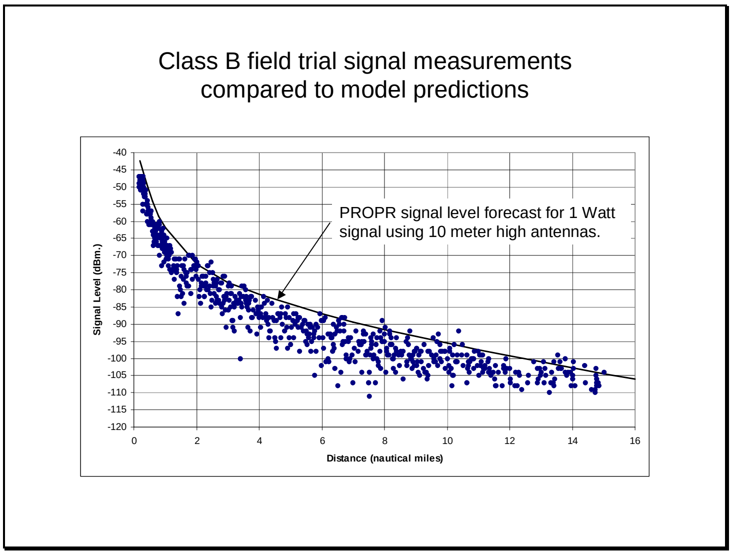
Propagation loss versus distance between simulation's AIS units.



Field trials of prototype Class B units have provided empirical signal measurements that are shown compared to the PROPR propagation-loss model in Figure 4. The measured signal levels are in good agreement with the model. However, there are a number of values that are 10 to 15 dB weaker than predicted. These additional losses and gains can be attributed to factors, such as, multi-path, temporary path blockage, sea surface conditions, antenna directivity caused by vessel structures, the effects of antenna directivity combined with platform motion, and temporary receiver desensitization by adjacent channel signals.

FIGURE 4

Class B signal level comparison between propagation model and field trials.



5 Simulation Results

A variety of alternative Class B methods and rules were proposed during development. A number of simulations were done to assess these proposals. Not all of these results are reported here. Reported here are the results supporting the proposed Class B method using CSTDMA as its performance compares to the existing alternatives – Class A and Class B using the methods in ITU-R M.1371.

Keeping in mind that all units in the simulation fully interact with each other, the simulation results are based upon the observations made from one of the units in the scenario. In order to improve the ability to compare the results of the different scenarios, the same unit is used as the “reference” or “observer” throughout all the simulation scenarios of a series – San Francisco or Florida. Since this unit is also a active participant in the simulation, it is sometimes a Class A unit while other times it is a Class B unit. When defined as a Class A unit, the scenario has 150 (or 351) Class A and 700 (or 1 904) Class B units. When defined as a Class B unit, the scenario had 149 (or 350) Class A and 701 (or 1 905) Class B units. This is noted in the tables.

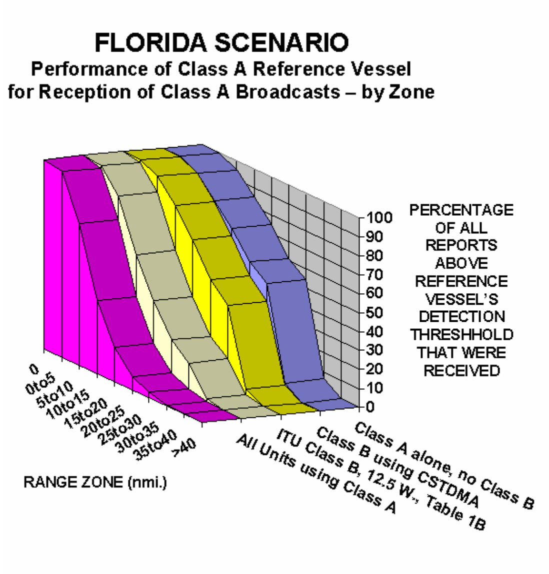
Simulation scenarios were also run using different units as the “reference vessel.” The resulting reception percentages were slightly different than those given here, but the trends of the relative performance differences remained the same as shown by the results reported here.

Each of the following figures is organized the same as Figure 1. They present reception performance for both the San Francisco and Florida scenarios from four perspectives covered in the following seven figures: how well Class A units receive other Class A units; how well Class A units receive Class B units; how well Class B units receive Class A units; and how well Class B units receive Class B units.

Broadcasts may not be received for one or more of three possible reasons. First, two or more signals are received simultaneously, and none of the signals is greater in strength by the co-channel interference level – set to 10 dB for all the scenarios. Second, the reference unit was transmitting at the time the broadcast arrived. Third, the broadcast is below the detection sensitivity of the unit – set to -107 dB for all the scenarios. This last reason is the primary reason why the performance drops quickly in the furthest “range zone” – signal drop-off at the radio horizon.

FIGURE 5

Performance Summary for Florida scenario, Class A reception of Class A units.



Percentage of possible Class A receptions that were correctly received aboard reference Class A vessel during indicated simulation scenarios.				
Distance from reference vessel (nm.)	351 Class A + 1904 Class A on non-SOLAS vessels	351 Class A + 1904 Class B (1371-1 12 Watt)	351 Class A + 1904 Class B (CSTDMA 1 Watt)	351 Class A alone
0 – 5	97.7	98.6	99.7	99.9
5 – 10	74.8	87.1	95.7	95.3
10-15	38.2	60.8	84.6	85.2
15-20	18.0	40.6	70.9	75.1
20-25	6.8	23.9	53.9	61.6
25-30	2.9	16.2	44.8	54.4
30-35	0.2	1.8	5.1	6.3

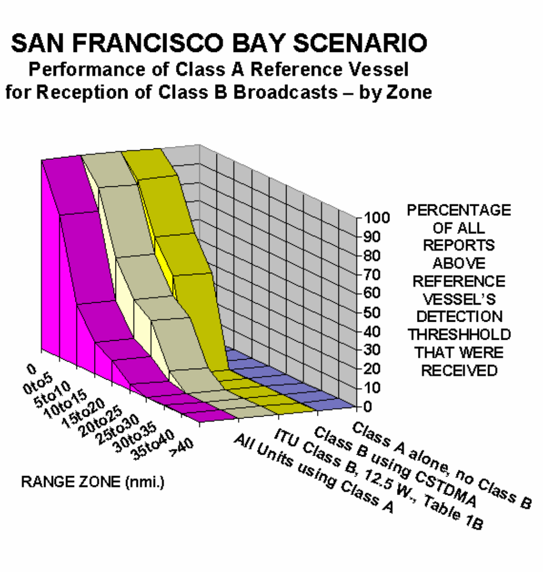
AIS coverage is often described as a "circular cell" similar to a cell created by the radio horizon. The size of the cell is said to shrink as activity on the AIS channels increases. However, the results of these simulations suggest that the size of the cell does not shrink. Rather, distant reception "thins." There always remains the possibility of long distance reception even during periods, or in areas, of heavy VDL loading conditions.

In the San Francisco Bay scenario, where all the units are Class A (See Figure 1), an average of 12 942 channel-slot broadcasts are made each frame. This could be considered an example of performance where loading is 2.9 times the maximum limit (12 942/4500).

The Class B CSTDMA unit attempts to use one of 10 randomly selected times to broadcast its report. If each of these times is determined to be occupied, the unit does not make a broadcast. A count was made for the number of times this occurred during the Florida scenario. The result was that 816 broadcasts out of 227 894 were not made – about 0.35%.

FIGURE 6

Performance Summary for San Francisco Bay scenario, Class A reception of Class B units.



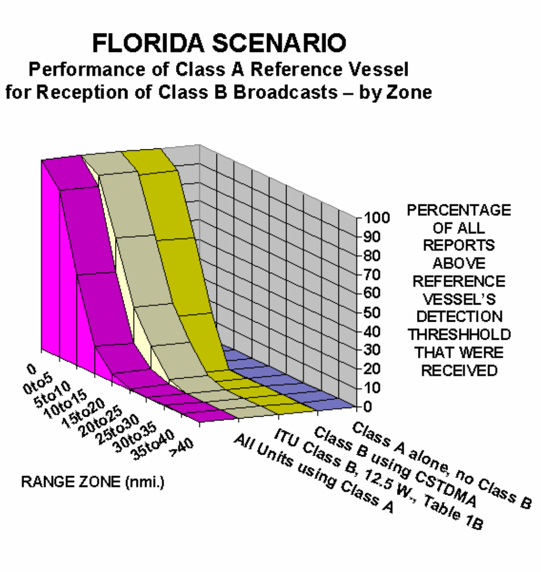
Percentage of possible Class B receptions that were correctly received aboard reference Class A vessel during indicated simulation scenarios.				
Distance from reference vessel (nm.)	150 Class A + 700 Class A on non-SOLAS vessels	150 Class A + 700 Class B (1371-1 12 Watt)	150 Class A + 700 Class B (CSTDMA 1 Watt)	150 Class A alone
0 – 5	74.9	87.3	89.9	
5 – 10	32.1	54.8	63.8	
10-15	16.2	36.7	47.2	
15-20	10.8	29.9	0	
20-25	2.3	7.6	0	
25-30	0	0	0	
30-35	0	0	0	

Although using lower power, the performance of the Class B CSTDMA in the San Francisco Bay scenario is slightly better than the Class B SOTDMA using high power. This holds true until the boundary of the Class B CSTDMA power-limited horizon is reached. This is probably due to the fact that the Class B CSTDMA "listen-before-transmit" strategy avoids interference from other signals. This strategy is less successful under the heavier loading conditions of the Florida scenario, Figure 7.

When the "351 Class A alone" scenario was run, the Class B unit's do not broadcast a signal. Therefore, the right column of the table is blank.

FIGURE 7

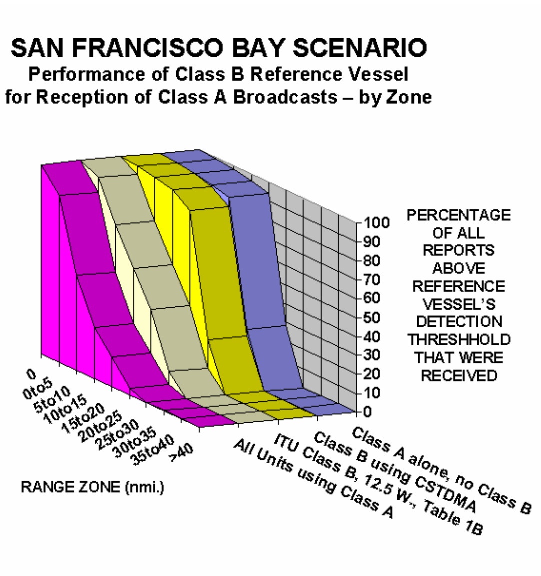
Performance Summary for Florida scenario, Class A reception of Class B units.



Percentage of possible Class B receptions that were correctly received aboard reference Class A vessel during indicated simulation scenarios.				
Distance from reference vessel (nm.)	351 Class A + 1904 Class A on non-SOLAS vessels	351 Class A + 1904 Class B (1371-1 12 Watt)	351 Class A + 1904 Class B (CSTDMA 1 Watt)	351 Class A alone
0 – 5	87.8	93.9	92.4	
5 – 10	47.2	65.1	61.5	
10-15	13.9	32.9	26.0	
15-20	4.1	16.4	0	
20-25	0.5	3.1	0	
25-30	0	0	0	
30-35	0	0	0	

FIGURE 8

Performance Summary for San Francisco Bay scenario, Class B reception of Class A units.



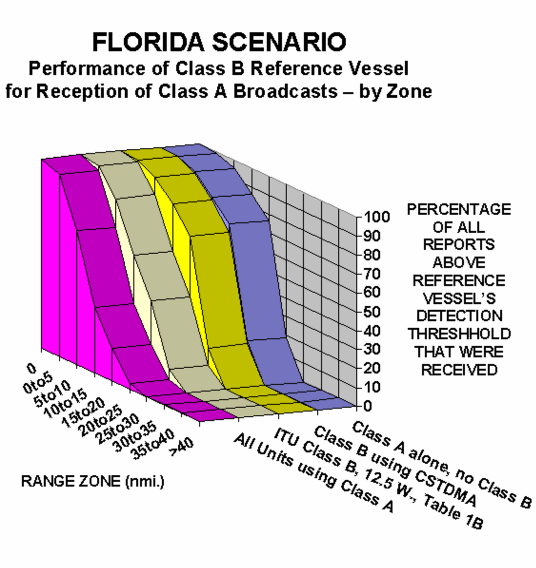
Percentage of possible Class A receptions that were correctly received aboard reference Class B vessel during indicated simulation scenarios.				
Distance from reference vessel (nm.)	149 Class A + 701 Class A on non-SOLAS vessels	149 Class A + 701 Class B (1371-1 12 Watt)	149 Class A + 701 Class B (CSTDMA 1 Watt)	149 Class A alone
0 – 5	87.6	95.4	99.4	99.4
5 – 10	49.7	74.5	97.9	97.9
10-15	26.8	55.8	95.4	96.3
15-20	15.4	38.5	88.8	94.1
20-25	3.3	10.0	24.9	28.4
25-30	0	0	0	0
30-35	0	0	0	0

Note the significant difference between the "Class B CSTDMA" reception performance in Figure 8 with the corresponding performance in Figure 6. The Class B units are able to receive Class A reports at distances significantly greater than the Class A unit's reception of the Class B units. This is primarily due to the difference in transmit power of each type of unit. This can also be seen by comparing Figures 9 and 7.

Also note how closely the Class B reception of Class A units closely follows the same performance curve with, or without, Class B CSTDMA transmissions – the right two columns of the table. This hold true for both the San Francisco Bay and Florida scenarios.

FIGURE 9

Performance Summary for Florida scenario, Class B reception of Class A units.

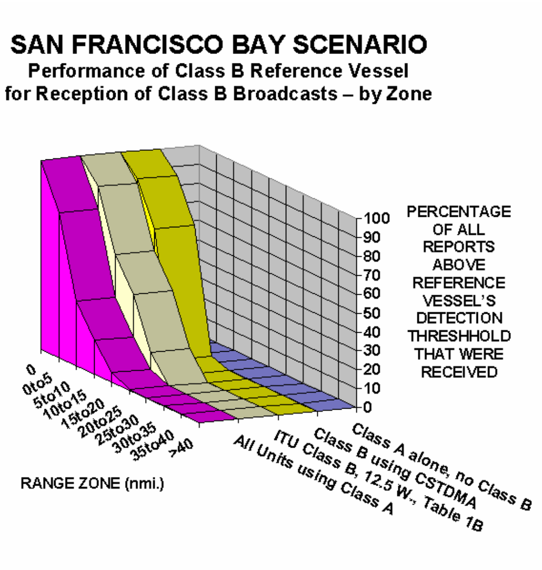


Percentage of possible Class A receptions that were correctly received aboard reference Class B vessel during indicated simulation scenarios.				
Distance from reference vessel (nm.)	350 Class A + 1905 Class A on non-SOLAS vessels	350 Class A + 1905 Class B (1371-1 12 Watt)	350 Class A + 1905 Class B (CSTDMA 1 Watt)	350 Class A alone
0 – 5	95.8	98.5	99.4	99.5
5 – 10	70.4	85.5	95.1	95.7
10-15	34.5	59.8	85.1	86.7
15-20	16.8	40.1	72.5	76.6
20-25	2.6	8.3	17.6	19.4
25-30	0	0	0	0
30-35	0	0	0	0

The comparison of the two Class B methods with respect to reception of other Class B units is interesting – Figures 10 and 11. The Class B using SOTDMA and 12.5 Watts outperforms the Class B using CSTDMA at distances beyond 10 miles. However, within 10 miles the performance of the two methods is virtually the same. This may be a result of several factors. The Class B CSTDMA uses fewer slots. It reports twice a minute. The Class B SOTDMA reports at the rates dictated by Table 1B in ITU-R M.1371-1 – up to a maximum of twelve times a minute. There may be more interference free time available for the Class B CSTDMA transmissions in that scenario, and the Class B CSTDMA units are designed to find those signal free time periods. Also, because the Class B SOTDMA treats candidate slots as "free" or unused when not externally allocated, it can be using garbled slots for transmissions. When slots become garbled under heavy channel loading conditions, the future external slot allocations (slot reservations) cannot be obtained and those slots remain "free" for candidate slot selection. The Class B CSTDMA avoids the use of garbled time periods.

FIGURE 10

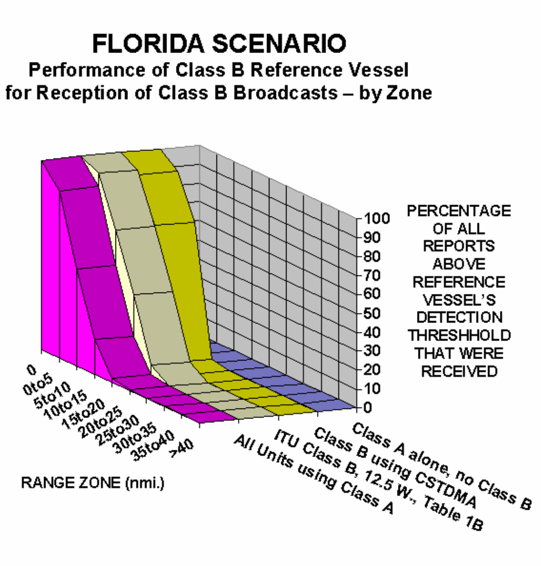
Performance Summary for San Francisco Bay scenario, Class B reception of Class B units.



Percentage of possible Class B receptions that were correctly received aboard reference Class B vessel during indicated simulation scenarios.				
Distance from reference vessel (nm.)	149 Class A + 701 Class A on non-SOLAS vessels	149 Class A + 701 Class B (1371-1 12 Watt)	149 Class A + 701 Class B (CSTDMA 1 Watt)	149 Class A alone
0 – 5	76.3	88.2	90.4	
5 – 10	33.8	56.6	68.4	
10-15	17.4	39.6	3.2	
15-20	4.7	13.7	0	
20-25	0	0	0	
25-30	0	0	0	
30-35	0	0	0	

FIGURE 11

Performance Summary for Florida scenario, Class B reception of Class B units.



Percentage of possible Class B receptions that were correctly received aboard reference Class B vessel during indicated simulation scenarios.				
Distance from reference vessel (nm.)	350 Class A + 1905 Class A on non-SOLAS vessels	350 Class A + 1905 Class B (1371-1 12 Watt)	350 Class A + 1905 Class B (CSTDMA 1 Watt)	350 Class A alone
0 – 5	88.2	95.2	92.7	
5 – 10	51.3	69.5	69.8	
10-15	17.7	39.4	2.1	
15-20	2.1	6.6	0	
20-25	0	0	0	
25-30	0	0	0	
30-35	0	0	0	

6 Summary

The simulation results indicate that Class B CSTDMA is compatible with existing AIS methods and provides a performance ratio that is higher than Class B SOTDMA – even under high channel loading conditions. In particular, the introduction of Class B CSTDMA will have less impact on existing Class A reception than will the use of Class B SOTDMA, thus providing an AIS access scheme that most closely adheres to the spirit of IMO Resolution MSC.140(76).

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