Automatic Identification System VHF Data Link Loading under Anomalous Tropospheric VHF Propagation

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***Abstract* — In paper the method for the VHF Data Link (VDL) loading estimation based on the processing of the "number of received stations" parameter of the "SOTDMA communication state" field of AIS messages No. 1, 2, 4 is proposed. Since the messages being processed contain the coordinates of the targets, it is also possible to build a map of the VDL loading. It is also shown that the VDL loading of Vessel Traffic Service (VTS) base stations for the Black Sea coast in conditions of anomalous propagation of radio waves can be 90% or more. The statistics of inconsistent AIS messages is considered.**

Keywords* — *Automatic Identification system (AIS), Vessel Traffic Service (VTS), Black Sea marine traffic, SOTDMA, VHF data link (VHD) loading, tropospheric index forecast map.

I. Introduction

The AIS (Automatic Identification System) is a system for the automated exchange of messages between vessels via radio waves using 2 channels on the frequencies 162.025 MHz and 161.975 MHz (VHF) which allows vessels and shore-based maritime surveillance systems to acquire a set of information (i.e. GPS coordinates, type of vessel, vessel registration, etc.) necessary for monitoring maritime traffic and analyzing activities at sea [1]. In AIS, SOTDMA (Self-Organized TDMA) protocol is used to resolve the problem of communication conflict without any control by the base station [2]. One frame of AIS information occupies one minute and is divided into 2250 time slots. One slot equals 26.67 ms. For the transmission bit rate is 9600 bps, a slot is 256 bits long. The frame starts or ends coinciding with the UTC time provided by GPS.

According to the ITU-R M.2123 the maximum range of AIS communication is usually determined by the mechanisms of radio wave propagation in the line-of-sight zone, as well as the diffraction of radio waves. With typical technical parameters of onboard and shore AIS equipment, the most reliable radio transmission over the sea surface is provided at distances up to 20–35 nautical miles, depending on the height of the antennas above sea level.

However, there are periods of anomalous atmospheric conditions when the AIS makes it possible to track vessels at much longer distances. Several ITU-R Recommendations address also the characteristics of a number of these mechanisms including: tropospheric scatter, atmospheric ducting, rain scatter, meteor burst, or sporadic-E. These phenomena can lead to overloading VHF digital link i.e. reducing ability of the onboard AIS equipment to find free time slots [10].

The overloading of the communication channel may disrupt the reliable identification of vessels, as well as the possibility of automatically obtaining the necessary data from the vessel (coordinates, speed, course, etc.), which will entail an increase in the delay in recognizing dangerous maneuvers of the vessels. The factors described above can significantly affect the safety of marine navigation.

This paper discussed the performance of AIS such as VHF digital link (VDL) loading under anomalous tropospheric VHF propagation.

II. VDL Loading

A. Super Long-Range Reception of AIS Signals

The Department of Programmable Electronics, Electrical Engineering and Telecommunications of the Admiral Makarov National University of Shipbuilding (NUOS) hosts two AIS stations provided by MarineTraffic: station No. 4757 is located in Mykolaiv on the building of the Institute of Automation and Electrical Engineering of the NUOS, and station No. 5064 is located in Ochakiv at the recreation center of the NUOS. Since August 2020, all messages received by stations are logged in the database in AIVDM-format.

Time intervals with medium and high signal reception ranges were taken for a detailed analysis. The number of AIVDM-sentences for the selected day is shown in Table 1 (the boundaries of the days correspond to UTC+3, the number of AIVDM sentences is slightly higher than the number of received binary AIS messages due to the presentation of some types of binary AIS messages in 2-3 AIVDM sentences).

TABLE I. AIVDM SENTENCES STATISTICS

Number of AIVDM sentences		
Date	***Mykolaiv***	***Ochakiv***
2021-06-11	203 424	129 904
2021-06-12	193 779	333 031
2021-06-29	235 638	368 518
2021-06-30	255 406	511 095
2021-07-01	184 952	834 898
2021-07-02	159 127	323 102
Total	1 232 325	2 500 548

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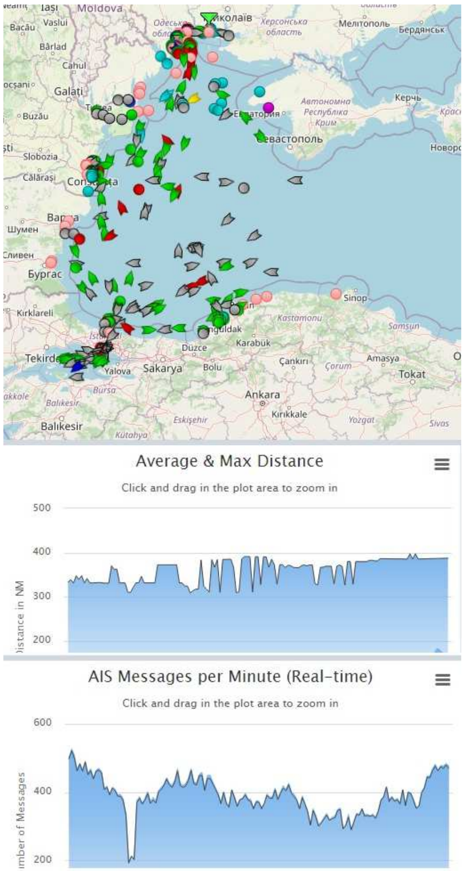

Fig. 1. AIS signal reception area at Ochakiv station on July 30, 2021

The difference in the number of received messages between the stations is due to three factors: the number of vessels in the near zone, whose signals are constantly received (this factor is often implemented in favor of the Mykolaiv station), the prevailing sea surface and the proximity of Ochakiv to the main sea routes in the Black Sea. The days of June 11 and 12 should be attributed to the normal conditions of radio wave propagation, on July 29, the number of received signals at the Ochakiv station began to increase, reaching a maximum on July 1, and ending on July 2. The signal reception area has reached the Sea of Marmara as shown in Fig. 1 (data refer to June 30).

The VHF signal reception area of station No. 5064 (Ochakiv) had a strong correlation with Hepburn Tropo Index (HTI) map (Fig. 2). The map shows the occurrence of potential duct paths. It should be noted that HTI is the predicted degree of deviation of tropospheric radio propagation in a certain area on a linear scale from 0 to 10. Thus, HTI is a measure of the total power of tropospheric radio signals and interference.

Thunderstorms or heavy rainfall may occur in areas with unstable tropospheric propagation. A change in the signal strength is also observed under the condition of the stability of the lower atmosphere and the instability of the middle and upper atmosphere, respectively. This can be traced at night, as well as before the advance of warm fronts.

The improvement of the propagation conditions did not affect the total number of received signals at the Mykolaiv station too noticeably, but the signal reception area has noticeably expanded (Fig. 3).

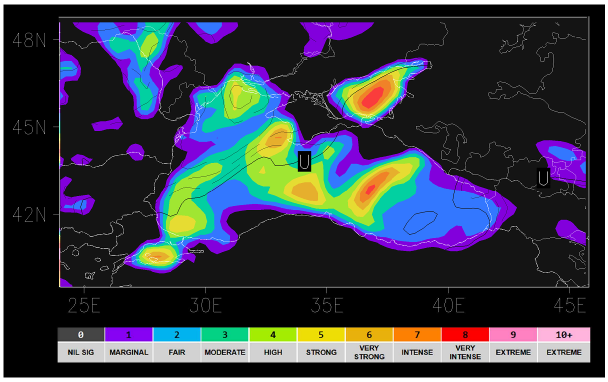

Fig. 2. Hepburn Tropo Index valid 15:00 UTC+3 July 30, 2021, Black Sea region (U – unstable signal areas)

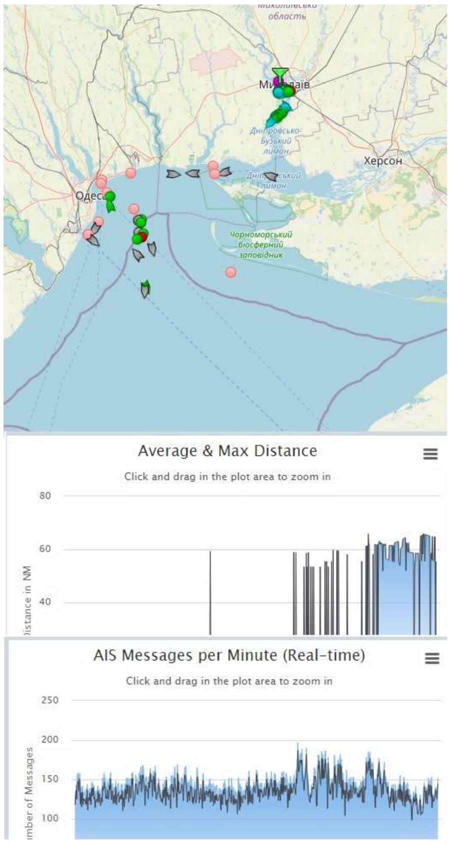

Fig. 3. AIS signal reception area at Mykolaiv station on July 30, 2021

B. VDL Loading Measurement and Estimation

Anomalous VHF tropospheric propagation can be a consequence of increased VDL loading and lead to degradation of maritime radio communications, which is described in Appendix 18 [9]: If the VDL loading exceeds 50% of the nominally available slot capacity during the last 4 minutes on both channels, this may affect the ability of the AIS mobile station to find free slots available for data transmission.

A simple and practical way to measure VDL loading is to calculate the sum of currently occupied slots in channel divided by the number of available slots, which is 2250 per TDMA frame. [6]. The result is usually expressed in percentage. This method can be used when the manufacturer of the AIS equipment supplies special utilities for monitoring the communication link.

The dynamic data of Class A vessels are sent in the form of position reports within the AIS message No. 1, 2, 3 as shown in Table 2 according to [5].

TABLE II. REPORTING INTERVAL FOR THE DYNAMIC DATA OF CLASS A VESSELS

Vessel's dynamic conditions	Nominal reporting interval
Vessel at anchor or moored and not moving faster than 3 knots	3 min
Vessel at anchor or moored and moving faster than 3 knots	10 s
Vessel 0-14 knots	10 s
Vessel 0-14 knots and changing course	3 1/3 s
Vessel 14-23 knots	6 s
Vessel 14-23 knots and changing course	2 s
Vessel > 23 knots	2 s
Vessel > 23 knots and changing course	2 s

Assuming according to the Table 2 that, on average, mobile stations will transmit messages every 10 seconds on alternating channels, i.e. average reporting interval $RI_{avg} = 10$ s, and that 2250 time slots per minute are available per channel, the responsible authorities should start monitoring the VDL when it is approaching 50% loading on any channel (375 targets within a 50 nautical mile range of an AIS shore station). The average VDL loading in percentage can be estimated using formula

$$VDL_{Loading} = N_t \frac{R_r}{2 \cdot 2250} \cdot 100\% \qquad (1)$$

where $R_r = 60/RI_{avg}$ – average report rate, $N_t = N_v + N_{bs}$ – number of targets (N_v – number of vessels and N_{bs} – number of base stations).

According to [5] AIS position report messages No. 1, 2 and base station report message No. 4 contain SOTDMA communication state. The SOTDMA communication state consists of the following parameters: sync state, slot time-out and sub message. When the parameter slot time-out of the SOTDMA communication state has one of the values three, five, or seven, the number of received stations (targets) should be contained within the SOTDMA communication state sub message.

Fig. 4 shows the number of received stations and estimated VLD loading in percentage using (1) for Vessel Traffic Service (VTS) base stations for the period from 2021-07-26 00:00:00 (UTC+3) to 2021-07-30 23:59:59 (UTC+3).

Table 3 shows that, for example, for VTS with MMSI 2723682 (Ochakiv) during anomalous tropospheric VHF propagation, the VDL loading increases from a minimum of 4.5% to a maximum of 89.6%. The peak VDL loading for this VTS was observed on 2021-07-29 19:45:00 UTC+3. An example of VDL loading map for this timestamp is shown in Fig. 6.

C. *Inconsistent AIVDM Messages*

When processing about 2 million AIVDM messages received from the AIS receiver No. 5064 (Ochakiv) within 5 days from 2021-07-26 00:00:00 (UTC+3) to 2021-07-30 23:59:59 (UTC+3) using histogram-based method, it was revealed that the maximum number of targets for base stations is 807, and for vessels – 865. At the same time, for three vessels with MMSI: 312481000, 271001058, 215417000, the maximum number of targets was clearly overestimated and amounted to 1446, 1639 and 12085, respectively. Statistics of inconsistent AIVDM messages are given in Table 4, and examples of these messages in Table 5.

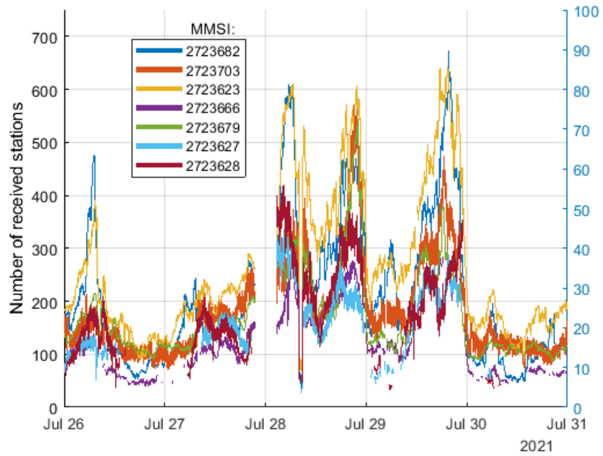

Fig. 4. Number of received stations and for VTSs for July 26, 2021 to July 30, 2021 inclusive (UTC+3)

TABLE III. VTS MAX AND MIN VDL LOADING

MMSI	Place	Latitude	Longitude	VDL Loading			
				Min		*Max*	
				Received stations	*%*	*Received stations*	*%*
2723666	Mykolaiv	46.6310	31.8588	40	5.3	307	40.9
2723679	Yuzhny	46.6011	31.0223	88	11.7	543	72.4
2723628	Kurortne	30.2865	30.2865	31	4.1	420	56
2723627	Zatoka	46.0740	30.4696	26	3.7	349	46.5
2723682	Ochakiv	46.6121	31.5506	34	4.5	672	89.6
2723623	Ochakiv	46.6008	31.5501	67	8.9	642	85.6
2723703	Yuzhny	46.6545	31.0337	70	9.3	570	76

TABLE IV. INCONSISTENT AIVDM SENTENCES STATISTICS

MMSI	Total messages	Min Received Stations	Max Received Stations
312481000	1787	957	1446
271001058	7	1541	1639
215417000	4977	11698, 0 (5 messages)	12087

In paper [4] the authors consider some mechanisms for the generation of inconsistent AIVDM messages, including those with incorrect coordinates. The reasons for such cases are failures in the operation of the onboard AIS transponder.

The transponder of the vessel with MMSI 215417000 in a short time (within 4 minutes) transmitted five messages with a zero number of targets (Fig. 5), while for other vessels (MMSI 312481000, 271001058) sharp jumps in the number of targets were not observed.

Responsible authorities should monitor such cases closely, because an unreliable transmission of the number of observed targets by a vessel can disrupt the stability of the SOTDMA network, since in the event of loss of accurate synchronization from the GPS system, the vessel with the largest number of observed targets potentially becomes a source of synchronization (semaphore).

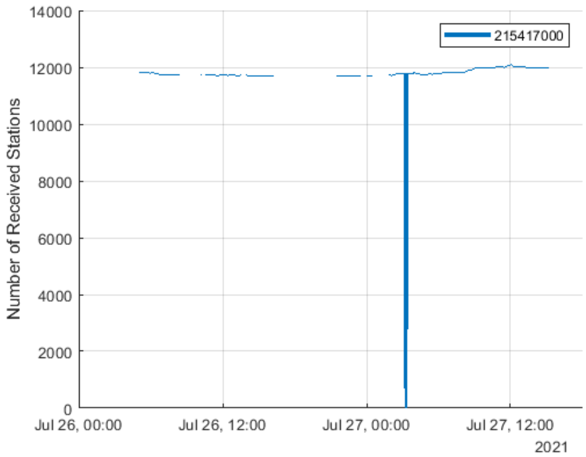

Fig. 5. Number of received stations for vessel with MMSI 215417000 for July 26, 2021 to July 27, 2021 inclusive (UTC+3)

TABLE V. EXAMPLES OF INCONSISTENT AIVDM MESSAGES

Timestamp	MMSI	AIVDM message	Received stations
2021-07-28 21:47:18 UTC+3	312481000	!AIVDM,1,1,,A,14b0Dr0016R<`o@IU6jGjn>N0<FV,0*0E	1446
2021-07-27 12:01:58 UTC+3	215417000	!AIVDM,1,1,,B,13=L0b0025R;5:0IKN6WaF7l0Fto,0*69	12087
2021-07-27 03:13:56 UTC+3	215417000	!AIVDM,1,1,,B,23=L0b0022R=HThJO:FVGm;b0D00,0*34	0
2021-07-29 17:11:20 UTC+3	271001058	!AIVDM,1,1,,B,142LUpP001R4QB4GcrOP04RT2<IW,0*00	1639

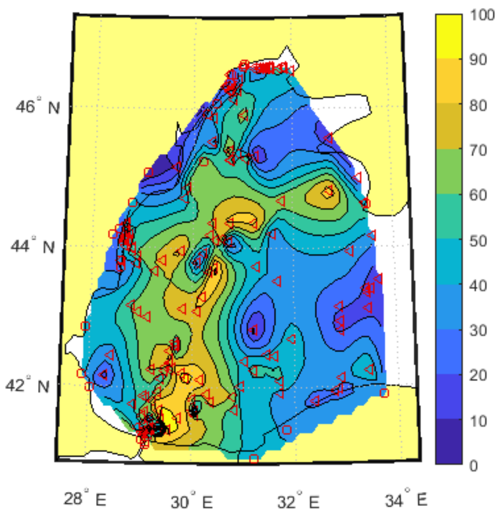

Fig. 6. Example of VDL loading map under anomalous tropospheric VHF propagation on 2021-07-29 19:45:00 UTC+3 (Δ – vessels, O – base stations)

III. CONCLUSIONS

1. The proposed method makes it possible to estimate the VDL loading for vessels and base stations (VTS) using an AIS receiver in its reception area. The method is based on the processing of the "number of received stations" parameter of the "SOTDMA communication state" field of AIS messages No. 1, 2, 4. Since the messages being processed contain the coordinates of the targets, it is possible to build a map of the VDL loading.

2. The VDL loading of base stations (VTS) for the Black Sea coast in conditions of anomalous propagation of radio waves can be 90% or more. Due to the correlation with the Hepburn Tropo Index (HTI), the HTI forecast maps can be used to make predictions of the VDL loading.

3. To reduce VDL loading under anomalous propagation of radio waves, it can be recommended to reduce the output power of AIS transponders at the command of base stations.

4. When processing of the dataset, incorrect operation of the AIS transponders was detected this manifests itself in the transmission of an overestimated number of targets in the “number of received stations” parameter.

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