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Area model in the radiocommunication event management system

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ABSTRACT

The paper presents a sea area model developed for the purposes of radio communication event management system in the maritime transport. The authors have presented the assumptions underlying the area model architecture, and proposed methods of modelling and presentation of dislocation of radio stations, taking into consideration their ranges. Wave propagation in sea areas has been analysed and a method of its presentation, based on an analysis of radio station ranges and feasibility of communications, has been proposed. The designed model incorporates ship-to-ship communications which are essential for messaging coast stations.

Keywords: radio communications, model dislocation, sea area

1. Introduction

The Global Maritime Distress Safety System (GMDSS) has been designed primarily to transmit distress signals from vessels to coast stations and the Marine Rescue Coordination Centres (MRCC) [1], [2], [11], [12]. The role of a GMDSS radio operator consists in monitoring, screening and verifying the incoming radio data stream. The pressure of processing large quantities of information, complex radio communications procedures and improper operation of equipment by GMDSS operators commonly render radio communications systems inefficient, ineffective, or even useless [10].

The Radio Communication Event Management System (RCEMS), which is being developed, offers a solution to the foregoing problems [4], [5]. An element which is crucial for an analysis of operation of the RCEMS is the development of a sea area model which takes into account the division of sea areas according to the Radio Regulations together with other factors affecting the communication process [5], [7].

There is a long list of factors determining ranges of GMDSS subsystems, including:

- the geographical location of dynamic objects (vessels, COSPAS-SARSAT satellites),
- the geographical location of stationary objects (coast stations, terrestrial satellite stations, geostationary satellites),
- technical and operational parameters of objects (heights of antennas, signal strength, radio emissions),
- time of day, season and solar activity, which have an effect of the width of ionospheric layers.

Operational requirements of the GMDSS subsystems, set out in the Radio Regulations, include definitions of sea areas [11]. However, the complex nature of radio wave propagation calls for an extension of the sea area model to include the elements presented in this paper [3].

2. Model structure elements

2.1. Definitions of sea areas as set out in the Radio Regulations

The GMDSS is based on the concept of using four marine communication sea areas to determine the operational, maintenance and personnel requirements for maritime radio communications. The definitions of the sea areas are present below:

1. **Sea area A1** means an area within the radiotelephone coverage of at least one VHF coast station in which continuous DSC alerting is available, as may be defined by a Contracting Government. Such an area could extend typically about 30 *nautical miles* (nm) from the coast station (SOLAS Chapter IV,Reg. 2-12).

2. **Sea area A2** means an area, excluding sea area A1, within the radiotelephone coverage of at least one MF coast station in which continuous DSC alerting is available, as may be defined by a Contracting Government. For planning purposes this area typically extends to up to 150 nm offshore, but would exclude any A1 designated areas. In practice, satisfactory coverage may often be achieved out to around 300 nm offshore (SOLAS Chapter, IV, and Reg. 2- 13).

3. **Sea area A3** means an area, excluding sea areas A1 and A2, within the coverage of an *International Mobile Satellite Organization* (Inmarsat) geostationary satellite in which continuous alerting is available, This area lies between about latitudes 76° north and 76° south, but excludes A1 and/or A2 designated areas (SOLAS Chapter IV,Reg. 2-14).

4. **Sea area A4** means an area outside sea areas A1, A2 and A3. This is essentially the Polar Regions, north and south of about 76° of latitude, but excludes any other areas (SOLAS Chapter IV,Reg. 2-15).

2.2. Numerical sea area model

The idea behind the presentation of data in the form of a grid (points, triangles, rectangles and trapezoids) is to arrange the data in a way enabling rapid localisation of a point (points) on a surface and its/their position relative to other points and areas on the same surface. On a grid, localisation is reduced to identifying the number of the element containing the point in question or – in special cases – the edge or corner (nod) which is the boundary between grid elements.

A sea area model can be developed with the use of an algorithm which enables discrete representation of the analysed area on a trapezoidal grid and further use of the grid in the modelling of dynamic situations [7], [8], [9].

In an analysis of dynamic situations, the grid structure is altered in consecutive time steps, depending on present positions of moving objects. The algorithm enables local modification of the grid relative to present positions of moving objects. At the same time, discrete representation of a sea area on a trapezoidal grid enables easy approximation of the areas which represent ranges of radio stations within particular bands, through the calculation of areas of trapezoids.

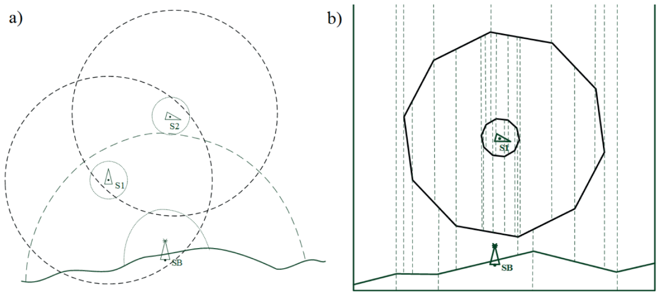

Fig. 1. Dislocation of radio objects, a) a situation, b) a numerical model of a radio station range [own study]

2.3. Sea area model based on V wave propagation conditions

Radio waves in V-band propagate linearly as spatial waves. They reflect from high-density objects and are subject to dispersion and attenuation in the atmosphere and other environments. Attenuation of ultra short waves in the troposphere results from the variability of meteorological phenomena and is caused mainly by the presence of various forms of water (precipitation, fog, etc.).

Modelling in sea conditions does not call for taking into consideration the terrain relief or buildings. However, one needs to take account of the effect of reflection of radio waves from the sea surface (multipath propagation).

In theory, the range of ultra short waves is restricted to the line-of-sight. In practice, however, it is much further thanks to the tropospheric refraction and diffraction. The range of V-band communications (in nautical miles) is expressed by means of the following equation [1]:

$$D = 2{,}5\left(\sqrt{h} + \sqrt{H}\right) \quad (1)$$

where:
h – height of the transmitting antenna,
H – height of the receiving antenna.

V-band communication range modelling consists in the determination of a circle of a radius D. In the event of communications with a coast radio station, whose antennas are located even several dozen meters above the ground surface, on some occasions only one-way communications may be possible. The ship's radio station will receive the signal transmitted by the coast station, but a signal transmitted from the ship will not be received.

2.4. Sea area model based on T wave propagation conditions

Propagation of radio waves in T-band depends on the time of day, being influenced by gas ionization in the ionosphere, caused by solar radiation.

At daytime, bounced-off waves are attenuated by the D layer and radio contact can be established via ground waves, whose range depends on the ground conductivity. Due to wave attenuation by the ground surface, the range of communication on land is limited, because the ground conductivity is much lower than that of sea water.

After sunset, the D and E layers disappear. Gas ionization in the ionosphere diminishes, making it possible to increase the range of communications with the use of bounced-off waves.

The range of T-band ground-wave communications is about 250 Nm during the day, and up to more than 1 000 Nm at night.

2.5. Sea area model based on U wave propagation conditions

The range of ground waves in the U-band is up to several dozen nautical miles. Therefore, communications in this band are carried out mostly by means of ionospheric waves. It is possible to communicate over a distance of 2,000 – 4,000 km with a single ionospheric reflection.

Thanks to M-type transmissions (which occur as a result of the appearance of the sporadic layer) or multihop transmissions, U-band waves can have a worldwide range.

When transmitted in the direction east-west, a radio wave may travel through daytime and night-time areas, what hinders the communication. If this is the case, propagation forecasts should be developed based on the time of day in the middle of the wave's path, or communication should be established at a time when the signal travels through an area of daytime or night-time throughout its path.

Communications with the use of reflected U waves are normally characterized by signal strength fading. Fading phenomena can be classified as interference fading, absorption fading, MUF skip fading.

The process of modelling radio station ranges for particular frequency ranges in T and U bands uses numerical area model-based methods. With the use of the finite element method, the electric field strength is determined, which is further used to determine the area in which the probability of establishing communication at a specified time is higher than the assumed minimum. Due to the random nature of many phenomena which have an effect on communications via bounced-off waves, the models developed and the range curves for particular bands are mere estimates. A range is determined in statistical terms only, based on the assumed probability of successful establishment of communication. Considering different properties for different wavelength ranges in the U band (4, 6, 8, 12, 16 MHz), each range should be analysed separately.

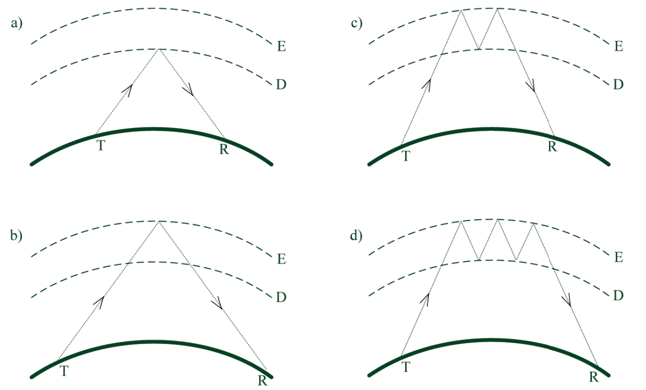

Fig. 2. Wave propagation distribution, a) T band, daytime, b) T band, night-time, c), U band, daytime, d) U band, night-time [own study]

A wave of a frequency f_0 transmitted vertically up bounces off at a specified height for which the electron density N reaches its peak value. The maximum frequency for which a wave bounces off the ionosphere layer at a height h is known as the critical frequency f_{cr}:

$$f_{cr} = \sqrt{80{,}5N(h)} \qquad (2)$$

where:
$N(h)$ – electron density for a height h.

The secant law applies to a wave of a frequency f, which reaches the ionosphere at an angle Θ_0:

$$f = \sqrt{80{,}5N(h)}\sec\theta_0 = \frac{f_0}{\cos\theta_0} = f_0\sec\theta_0 \qquad (3)$$

By increasing the frequency to a value where $f_0 = f_{cr}$, the maximum usable frequency f_{max} (MUF) is obtained, for which communications between two points in specified conditions is possible, with a 50% wave reflection probability:

$$f_{\max}(\theta) = f_{cr}\sec\theta_0 \qquad (4)$$

For example, for the E layer at a height of 100 km:

$$f_{\max E} = 3{,}2 f_{cr} \qquad (5)$$

In the development of radio communications systems the optimal frequency of traffic f_{FOT} (FOT) is used, with a 90% probability of wave reflection.

$$f_{FOT} = 0{,}85 f_{max} \qquad (6)$$

The lowest usable frequency (LUF) in which the establishment of communication is possible in the conditions of signal attenuation in the ionosphere is also determined.

2.6. INMARSAT satellite system-based sea area modelling

Modelling of communications in satellite bands requires taking into consideration the properties of each subsystem. In the INMARSAT C subsystem, which uses omnidirectional antennas, only the antenna's (vessel's) position needs to be determined, which next serves a basis for the determination in which of the four areas covered by INMARSAT C the ship's radio station is and the selection of the corresponding satellites for logging in.

In the INMARSAT B and Fleet subsystems, which use parabolic directional antennas, discretized diagrams must be additionally used, which enable the determination of the antenna's settings (the azimuth and elevation angle) for a particular vessel position.

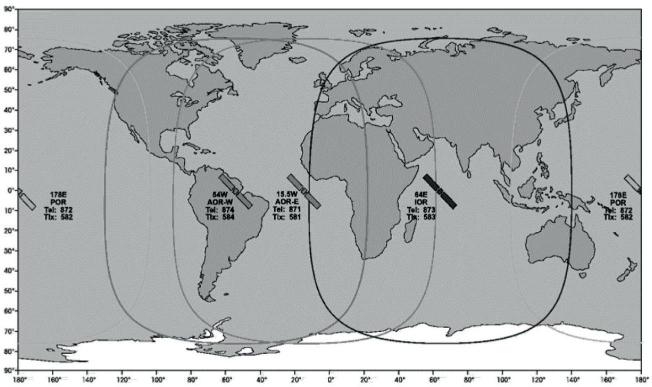

Fig. 3. INMARSAT satellite ranges [own study]

Figure 3 presents a map with ranges of particular satellites in the INMARSAT system. The circles mark the boundaries when the elevation angle at which the satellite is visible is greater than 5 degrees, as only then reliable emergency communication may be established. In practice, communications via INMARSAT satellites can be established when the elevation angle is smaller. However, in difficult hydrological and meteorological conditions, the probability of disturbances to emergency communications rises substantially [1], [11].

2.7. Sea area model based on ship-to-ship and ship-to-coast station relations

In order to work out ranges of communications for particular subsystems, it is necessary to take into consideration the parameters of objects, such as vessels, coast stations and satellite stations. It means that each object has its own model of ranges, which depends on the time (time of day and season) and parameters of other objects, e.g. the height of the VHF radiotelephone antenna used by the message receiver. Each object has its own sea area model, consisting of many layers and taking into consideration the availability or non-availability of communications with other objects. A sea area model can be presented as a vector of structures **S**:

$$\mathbf{S} = (S_1, \dots S_N) \tag{7}$$

where:
N – number of objects considered in the model,
S_i – characteristic structure of the i^{th} object,
i – number of object (ship, coast station, satellite station).

Structure S_i can be presented by means of the following formula:

$$S_i = \langle \lambda_i(t), \phi_i(t), T_{i,j,k}(t) \dots \rangle \tag{8}$$

where:
$l_i(t), f_i(t)$ – geographical coordinates of the i^{th} object, variable over time,
$T_{i,i,k}$ – availability matrix for communications between the ith object and the k^{th} object via the j^{th} channel, variable over time.

The communications channel in the model in question is the consecutive communication subsystem with distinct bands. For example, the HF radiotelephony is a GMDSS subsystem, but communications channels in the subsystem are consecutive bands 4, 6, 8 12, 16, 18/19 22, 25/26 MHz. It can be assumed that values of the availability matrix $T_{i,,j,k}$ are random variables of discrete values. Value "1" means that communications with the k^{th} object can be established via the j^{th} channel. Value "0" means that communications with the k^{th} object cannot be established via the j^{th} channel. Values of the $T_{i,,j,k}$ matrix, although discrete (as assumed for the purpose of the model) are random variable over time. The communications channel corresponding to the MF band radiotelephony communications may serve as an example here – its range during the night is greater than at daytime. The $T_{i,,j,k}$ matrix element for $i = k$ indicates that the communications channel on the i^{th} object is switched on (value 1) or off (value 0).

Figure 4 presents an example of three vessels (objects S_2, S_3, S_4) and one coast station (object S_1). Let us assume that heights h of V-band radiotelephone antennas for particular objects are, consecutively: 150 m, 90 m, 9 m and 4 m. Table 1 presents heights of antennas on the objects and ranges between them, calculated with the use of formula (1).

Table 1. Heights of objects' antennas and ranges between them [own study]

h [m]	H [m]	Ranges [Nm]
150	90	54,34
150	9	38,12
150	4	35,62
90	9	31,22
90	4	28,72
9	4	12,5

Figure 4 shows positions of object S_1 – coast station and three vessels $S_2 \div S_4$, as well as circles marking radio ranges for objects S_1 and S_3, which depend on the height of the message receiver's antenna location (h), as specified in Table 1. For clarity and an easy analysis, all objects are located along a straight line. It follows from the drawing that object S_1 (coast station) can establish communications with objects $S_2 \div S_3$. However it cannot establish communications with object S_4. Object S_3, a vessel, can communicate with vessel S_2, but it cannot communicate with vessel S_4, in spite of the fact that its distance to S_3 is shorter than to S_2. In this example, communications between the coast station S_1 and vessel S_4, and between vessels S_3 and S_4, are not available due to the height at which the antenna of vessel S_4 is located.

If the communications channel corresponding to the radiotelephony communications over V band is marked $j = 1$, values of the communications availability matrix $T_{i,j,k}$ for the example presented in figure 4 are as follows:

$$\begin{aligned} T_{112} &= T_{211} = 1 \\ T_{113} &= T_{311} = 1 \\ T_{114} &= T_{411} = 0 \\ T_{213} &= T_{312} = 1 \\ T_{214} &= T_{412} = 0 \\ T_{314} &= T_{413} = 1 \end{aligned} \tag{9}$$

An analysis of the drawing and the communication availability matrix shows that the stream of objects – vessels and coast stations in a particular sea area, as well as their technical and operational properties, must be taken into consideration in the development of that sea area model [6].

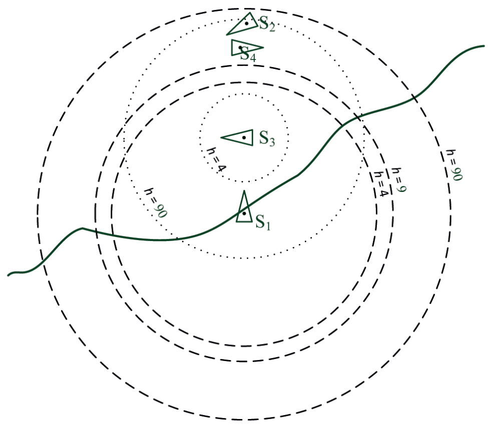

Fig. 4. Example dislocation of radio objects in V band, with circles marking ranges [own study]

3. Conclusion

The article presents sea area models for various subsystems and types of objects. To conclude:

- In order to analyse complex processes in communication event management systems, it is necessary to develop sea area models which take into consideration various factors.
- The most important sea area model is the model based on the definitions of sea areas A1, A2, A3 and A4 set out in the Radio Regulations.
- The models of sea areas based on the definitions set out in the Radio Regulations are limited, as they do not take into account variable over time wave propagation conditions or parameters of objects participating in the communication process – hence the need to extend the sea area model.
- Each object located in a sea area contributes additional layers to the model.
- Sea area modelling calls for taking into consideration an object stream model.
- The sea area model elements proposed in the article enable modelling of complex processes in communication event management systems.

Considering high complexity of a sea area model, it is necessary to consider various factors in the design and operation of radio communication event management systems.

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