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Radiocommunication event allocation model for a selected sea area

Marcin Mąka, Piotr Majzner ✉, Andrzej Lisaj

Maritime University of Szczecin
1-2 Wały Chrobrego St., 70-500 Szczecin, Poland
e-mail: {m.maka; p.majzner; a.lisaj}@am.szczecin.pl
✉ corresponding author

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Abstract
This article presents the structure of a model of the allocation of radiocommunication events at coastal radio stations, land-based satellite stations and on vessels in sea area A3. The propagation of radio waves in the HF band has been analyzed to examine the range of various radio stations and their capabilities of establishing communication between each other. We also present methods of modeling and displaying the deployment of individual stations, of presenting radiocommunication events as a function of time using time diagrams, as well as the manner of the chronological presentation of radiocommunication events and related decisions. It has been shown that there is a relationship between the effectiveness of communication and propagation conditions that is strongly dependent on the time-of-day. We present the need to develop a decision support system for the radio operator on the bridge.

Introduction

The main task of the GMDSS system is to send signals from ships in distress to coastal radio stations and Rescue Coordination Centers (RCC) (Salmonowicz, 2001; Czajkowski, 2002). During vessel operation, the GMDSS equipment user manages streams of information coming in *via* the radio. These data are essential for the proper functioning and operation of the ship, since they provide a basis for making many navigation-related decisions. In previous publications (Lisaj & Majzner, 2014; Lisaj, Majzner & Mąka, 2015; Lisaj, Mąka & Majzner, 2015) the authors have shown that having to manage a large amount of information makes the GMDSS system inefficient and ineffective.

We present the deployment of mobile radio stations (vessels) and coastal stations and the terrestrial Inmarsat satellite system covering the sea area A3. 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 approximately between latitudes 76° north and 76° south, but excludes A1 and/or A2 designated areas (SOLAS Chapter IV, Reg. 2-14). The presentation of the information streams flowing between objects *via* the GMDSS system takes into account the type of radio high frequency bands, the Inmarsat system and the direction of data transmission.

The developed model of event allocation is an integral part of the model of Radiocommunication Events Management System, which assists a GMDSS operator in selecting and verifying the incoming information and, on this basis, making the right decisions (Lisaj & Majzner, 2014; Majzner & Lisaj, 2014; Mąka, Lisaj & Majzner, 2014). The model is used in modelling information flow and a situation within the sea area A3, and the presentation of the situation.

To enable proper implementation of the tasks and situation modeling it is necessary to take into account the relevant regulations and procedures of the Radio Regulations, the SOLAS and STCW Conventions, and the chronology of radiocommunication events in reference to a particular radio station and systems.

The process of building an allocation model assumes that all station operators act in compliance with the provisions of the SOLAS and STCW Conventions and the Radio Regulations, which also set the requirements to be met by ships and the GMDSS operators (IAMSAR, 2001; SOLAS, 2009; Uriasz & Majzner, 2013).

The authors take account of the radio-communication subsystems which vessels engaged in shipping in the sea area A3 are obligated to carry. These include:

- DSC HF,
- HF radio telephony,
- Inmarsat C,
- EGC system – SafetyNet.

U-band wave propagation and area modelling in the sea area A3

Modelling the phenomena occurring during the propagation of radio waves in the U (HF) frequency band and the determination of the practicable communications range under preset conditions require a number of factors to be considered:

- time-of-day,
- distance between radio stations,
- season of the year,
- cycle of solar activity,
- atmospheric conditions.

Due to the random nature of atmospheric conditions and changes in solar activity, the radio range determination has a dynamic and probabilistic character.

The phenomenon of radio wave propagation in the frequency band U (HF) is largely dependent on the time-of-day. This follows directly from the phenomena occurring in the ionosphere (ionization of gases) under the influence of solar radiation.

Figure 1 illustrates the relationship between the radiotelephony range for 2, 4, 6, and 8 MHz bands as a function of the time-of-day according to local time. Figure 2 presents the communications range for 12 MHz and 16 MHz bands with Lower User Frequencies (LUF) and Maximal User Frequencies (MUF). For MUF, two wave propagation directions are taken into account: east (E) and west (W). These data were obtained from a Transas simulator

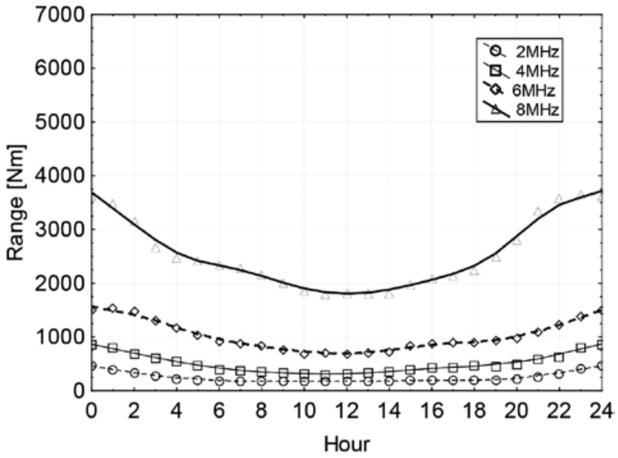

Figure 1. Ranges of 2–8 MHz frequencies as a function of hour of day

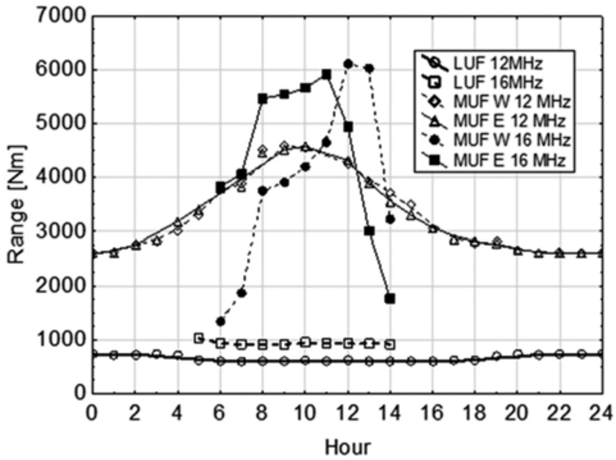

Figure 2. Ranges of 12–16 MHz frequencies as a function of hour of day

TGS 5000, with an implemented mathematical model of propagation, recommended by the International Telecommunication Union (ITU).

It follows from the charts that for the 2–8 MHz band, the range decreases towards 12 noon, while at the same time it increases for 12 and 16 MHz bands. At night time, the opposite is true – during night hours the range of bands below 8 MHz lengthens, whereas the 8 MHz band decreases. In addition, we can observe in Figure 2 a strong influence of direction in which the electromagnetic wave propagates – the propagation range in the western direction remains at a higher level for a longer period of time, whereas the eastern propagation rapidly decreases immediately after 1200 hours. For the 16 MHz band, it is greater at around 1200 hours than is the 12 MHz band, but there is no practical possibility of establishing communications in the 16 MHz frequency band in the night, while it is possible in the 12 MHz band.

Radio station operation area modelling in the sea area A3

It is assumed for the model presented in Figure 3 that the ship in distress is located in the middle of the ocean, approximately 1000 Nm east and west of the coast stations S4 and S6. The discussed model research area bears some parallels to the situation in the North Atlantic. It is further assumed that the coast station S4 and satellite ground station S5 cooperate with the same Rescue Coordination Centre. Also, stations S6 and S7 cooperate with the closest Rescue Coordination Centre.

Let us assume that ships S1 and S3 are at some distances from the ship S0:
- S1 – 100 Nm,
- S2 – 600 Nm,
- S3 – 1000 Nm.

Due to the range of short wave band varying as a function of time-of-day, two situations are considered, where a vessel in distress sends an alert at:
- 00.00 UTC,
- 12.00 UTC.

There are three possible situations in which the radio operator on ship S0:
1. Transmits only a distress alert in the HF band using a Digital Selective Calling (DSC).
2. Performs only a distress alert using the Inmarsat C terminal.
3. Performs both DSC distress alert in the HF band and via the Inmarsat C system.

The subject of this analysis is the third, most likely situation, in which distress alerts are sent *via* DSC and the Inmarsat system. In this situation, the radio operator on ship S0 sends a distress alert by DSC in one of the high frequency bands. Due to the varying, time-of-day dependent range of communication it becomes necessary to adopt a multi-variant choice of emergency communication in the 4 MHz to 12 MHz band.

A distress alert by DSC sent by a ship in distress lasts for approximately 35 seconds. After approximately 45 seconds the radio operator sends to station S5 a simplified alarm by the Inmarsat C terminal. Without waiting for the acknowledgement from one of the coast stations S4 or S6, the radio operator makes a distress call by radiotelephone in an appropriate frequency band, in which a DSC distress alert was sent.

After approximately 3 minutes following receipt of the alert, the Rescue Coordination Centre, connected with station S5, sends to ship S0 a query to ascertain that ship S0 is indeed in distress. Ship S0, using an Inmarsat C terminal, again sends a distress message. Upon receipt of a repeated alert from the ship in distress, the Rescue Coordination Centre connected with station S5 by Enhanced Group Calling (EGC) notifies all vessels on the ocean. We assume

Figure 3. Deployment and ranges of a radio station in sea area A3

that only ship S1 is able to effectively provide assistance to ship S0.

The model of the message transmission and reception process makes use of a matrix of information receipt availability – $T_{i,j,k}$ (Majzner & Mąka, 2013; Lisaj, Majzner & Mąka, 2015). The matrix determines the availability of reception of a message received by the i-th object, sent by the k-th object using the j-th communications system. In stationary conditions, the matrix takes the values '0' – no information can be received, and '1' – information can be received. It was assumed that the individual subsystems have the following variable value j:

DSC HF 4 MHz: $j = 0$, RTL HF 4 MHz: $j = 1$
DSC HF 6 MHz $j = 2$, RTL HF 6 MHz: $j = 3$
DSC HF 8 MHz: $j = 4$, RTL HF 8 MHz: $j = 5$
DSC HF 12 MHz $j = 6$, RTL HF 12 MHz: $j = 7$
DSC HF 16 MHz $j = 8$, RTL HF 16 MHz: $j = 9$
Inmarsat C: $j = 10$

If the ship in distress sent an alarm at approximately 0000 hours local time, the matrix elements $T_{i,j,k}$ will assume these values:

$$T_{i=0} = \begin{bmatrix} 11100000 \\ 11100000 \\ 11111010 \\ 11111010 \\ 11111010 \\ 11111010 \\ 10011010 \\ 10011010 \\ 10000000 \\ 10000000 \\ 10000101 \end{bmatrix}, T_{i=1} = \begin{bmatrix} 11100000 \\ 11100000 \\ 11111010 \\ 11111010 \\ 11111010 \\ 11111010 \\ 01011010 \\ 01011010 \\ 01000000 \\ 01000000 \\ 01000101 \end{bmatrix}, T_{i=2} = \begin{bmatrix} 11100000 \\ 11100000 \\ 11111010 \\ 11111010 \\ 11111010 \\ 11111010 \\ 00101000 \\ 00101000 \\ 00100000 \\ 00100000 \\ 00100101 \end{bmatrix}$$

$$T_{i=3} = \begin{bmatrix} 00010000 \\ 00010000 \\ 11111010 \\ 11111010 \\ 11111010 \\ 11111010 \\ 01011010 \\ 01011010 \\ 00010000 \\ 00010000 \\ 00010101 \end{bmatrix}, T_{i=4} = \begin{bmatrix} 00001000 \\ 00001000 \\ 10011000 \\ 10011000 \\ 11111010 \\ 11111010 \\ 01011010 \\ 01011010 \\ 00001000 \\ 00001000 \\ 00000000 \end{bmatrix}, T_{i=5} = \begin{bmatrix} 00000000 \\ 00000000 \\ 00000000 \\ 00000000 \\ 00000000 \\ 00000000 \\ 00000000 \\ 00000000 \\ 00000000 \\ 00000000 \\ 11110000 \end{bmatrix}$$

$$T_{i=6} = \begin{bmatrix} 00000010 \\ 00000010 \\ 11010010 \\ 11010010 \\ 11111010 \\ 11111010 \\ 00011010 \\ 00011010 \\ 00000010 \\ 00000010 \\ 00000000 \end{bmatrix}, T_{i=7} = \begin{bmatrix} 00000000 \\ 00000000 \\ 00000000 \\ 00000000 \\ 00000000 \\ 00000000 \\ 00000000 \\ 00000000 \\ 00000000 \\ 00000000 \\ 11110000 \end{bmatrix} \qquad (1)$$

Where the ship in distress sent an alarm at approximately 1200 hours local time, the matrix elements $T_{i,j,k}$ will assume these values:

$$T_{i=0} = \begin{bmatrix} 11000000 \\ 11000000 \\ 11111010 \\ 11111010 \\ 11111010 \\ 11111010 \\ 10011010 \\ 10011010 \\ 10011010 \\ 10011010 \\ 10000101 \end{bmatrix}, T_{i=1} = \begin{bmatrix} 11000000 \\ 11000000 \\ 11111010 \\ 11111010 \\ 11111010 \\ 11111010 \\ 01011010 \\ 01011010 \\ 01000000 \\ 01000000 \\ 01000101 \end{bmatrix}, T_{i=2} = \begin{bmatrix} 01100000 \\ 01100000 \\ 11111010 \\ 11111010 \\ 11111010 \\ 11111010 \\ 00101000 \\ 00101000 \\ 00100000 \\ 00100000 \\ 00100101 \end{bmatrix}$$

$$T_{i=3} = \begin{bmatrix} 00010000 \\ 00010000 \\ 11111010 \\ 11111010 \\ 11111010 \\ 11111010 \\ 11111010 \\ 11111010 \\ 11011000 \\ 11011000 \\ 00010101 \end{bmatrix}, T_{i=4} = \begin{bmatrix} 00001000 \\ 00001000 \\ 00011000 \\ 00011000 \\ 11111010 \\ 11111010 \\ 11011010 \\ 11011010 \\ 01001010 \\ 01001010 \\ 00000000 \end{bmatrix}, T_{i=6} = \begin{bmatrix} 00000010 \\ 00000010 \\ 11110010 \\ 11110010 \\ 11111010 \\ 11111010 \\ 11011010 \\ 11011010 \\ 10000010 \\ 10000010 \\ 00000000 \end{bmatrix} \qquad (2)$$

For the Inmarsat system, propagation conditions do not change with time-of-day, so matrices $T_{i=5} = T_{i=7}$ take the same values as in matrices (1). For $i = k$, the value $T_{i,i,k}$ means for the i-th object that an appropriate communications device for j-th subsystem is switched on or off, respectively.

Modelling the radiocommunication events chronology

The modelling and presentation of incoming and outgoing messages for each station makes use of time diagrams.

The Y axis in the diagrams represents the communications subsystems of each station. For better transparency, Figures 4 and 5 illustrate only diagrams for three of the subsystems used: DSC in the 6 MHz frequency band ($j = 3$), radiotelephony in the 6 MHz band ($j = 4$) and Inmarsat C ($j = 10$). All the selected transmissions (TX) and receptions (RX) of messages are marked by different color stripes.

Figure 4 illustrates diagrams for 0000 hours local time, Figure 5 for 1200 hours local time.

The diagrams also show that some messages informing of the same event are doubled, as received from various GMDSS subsystems.

Diagrams for the other subsystems, not depicted in Figures 4 and 5, show a strong dependence of communications range on the time-of-day. For example,

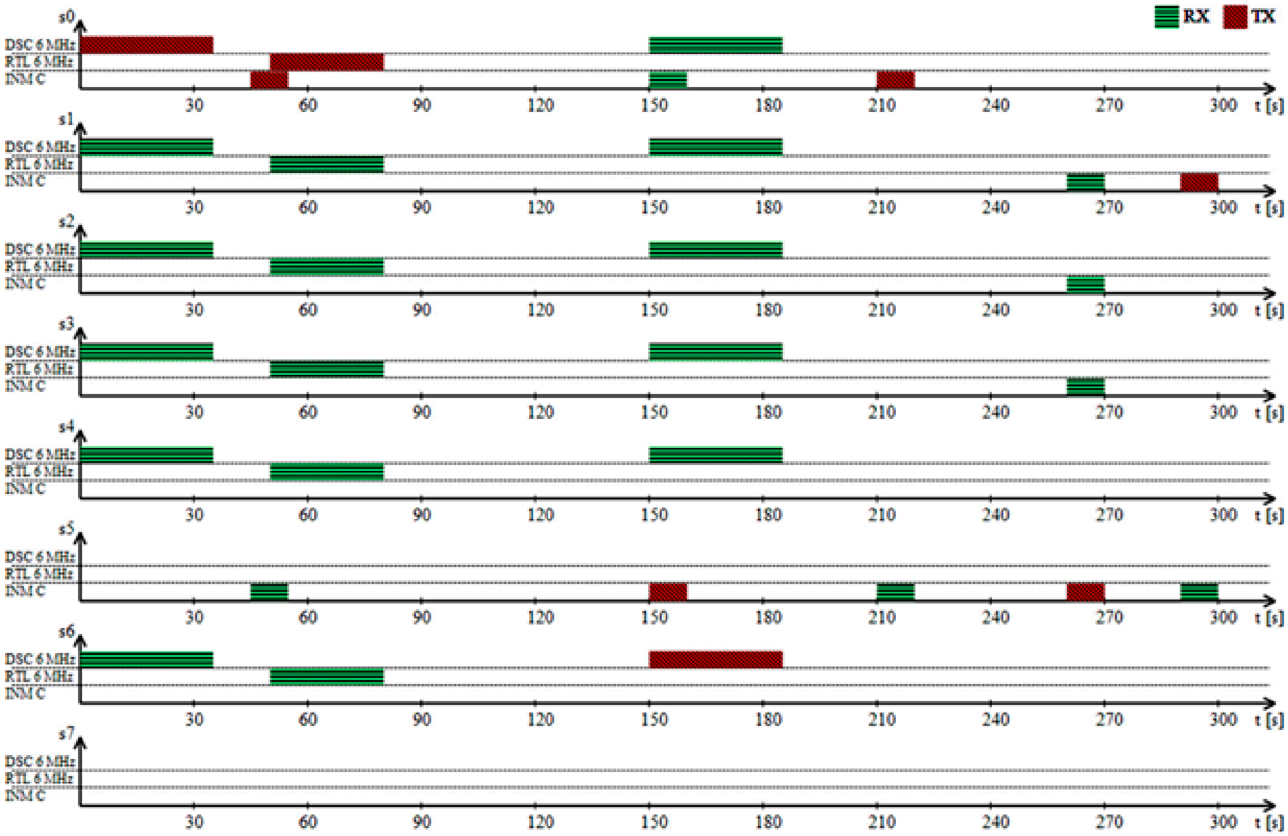

Figure 4. Time diagram presenting an extract from an emergency communication in sea area A3 at 0000 local time

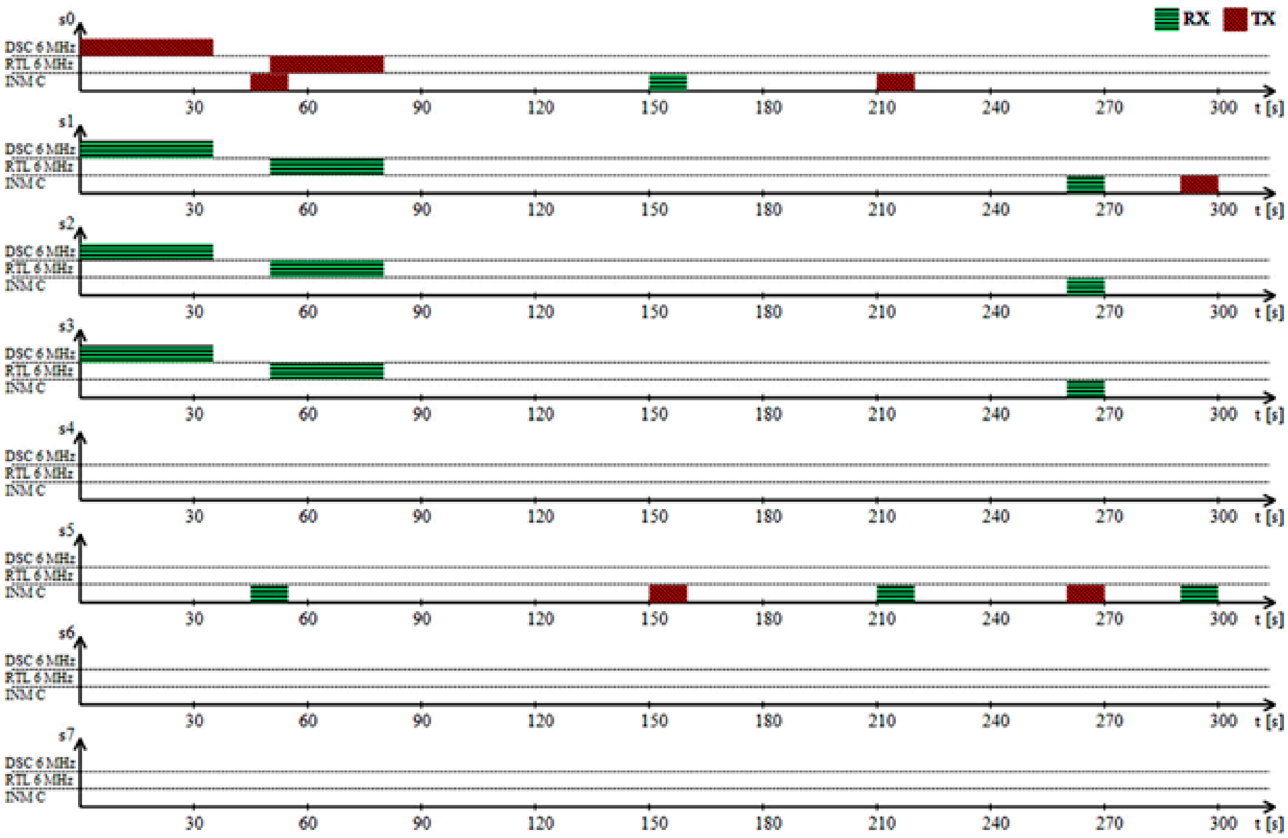

Figure 5. Time diagram presenting an extract from an emergency communication in sea area A3 at 1200 local time

an alert sent by ship S0 in the 12 or 16 MHz bands would be picked up by the coast stations S4 and S6 at 1200 local time, and would not be picked up during night hours. This shows a strong dependence of alarm effectiveness of various GMDSS subsystems on the time-of-day. The Inmarsat system is, in this case, independent of the time-of-day. In addition, the values of the $T_{i,j,k}$ information availability matrix indicate that the ships at a distance shorter than the range determined by the LUF line in Figure 2 will not receive an alert from ship S0, but it will be picked up by ships farther away.

We can note from the diagrams and Figure 3 that the operator of ship S0 can send an alarm *via* the Inmarsat to the LES station, not connected with RCC co-operating with the coast station that received and acknowledged the alarm by a DSC system. This may cause a simultaneous launch of rescue operation by two RCCs.

Decision-making process modelling

Figure 6 illustrates a diagram of the decision-making process in a situation herein discussed for ship S1 at 0000 hours local time. Such diagrams should be drawn up for all ships and the coast station, but only ship S1 is able to provide effective assistance. On the left-hand side of Figure 6, the time axis includes marked communication events, with the corresponding systems and frequency used.

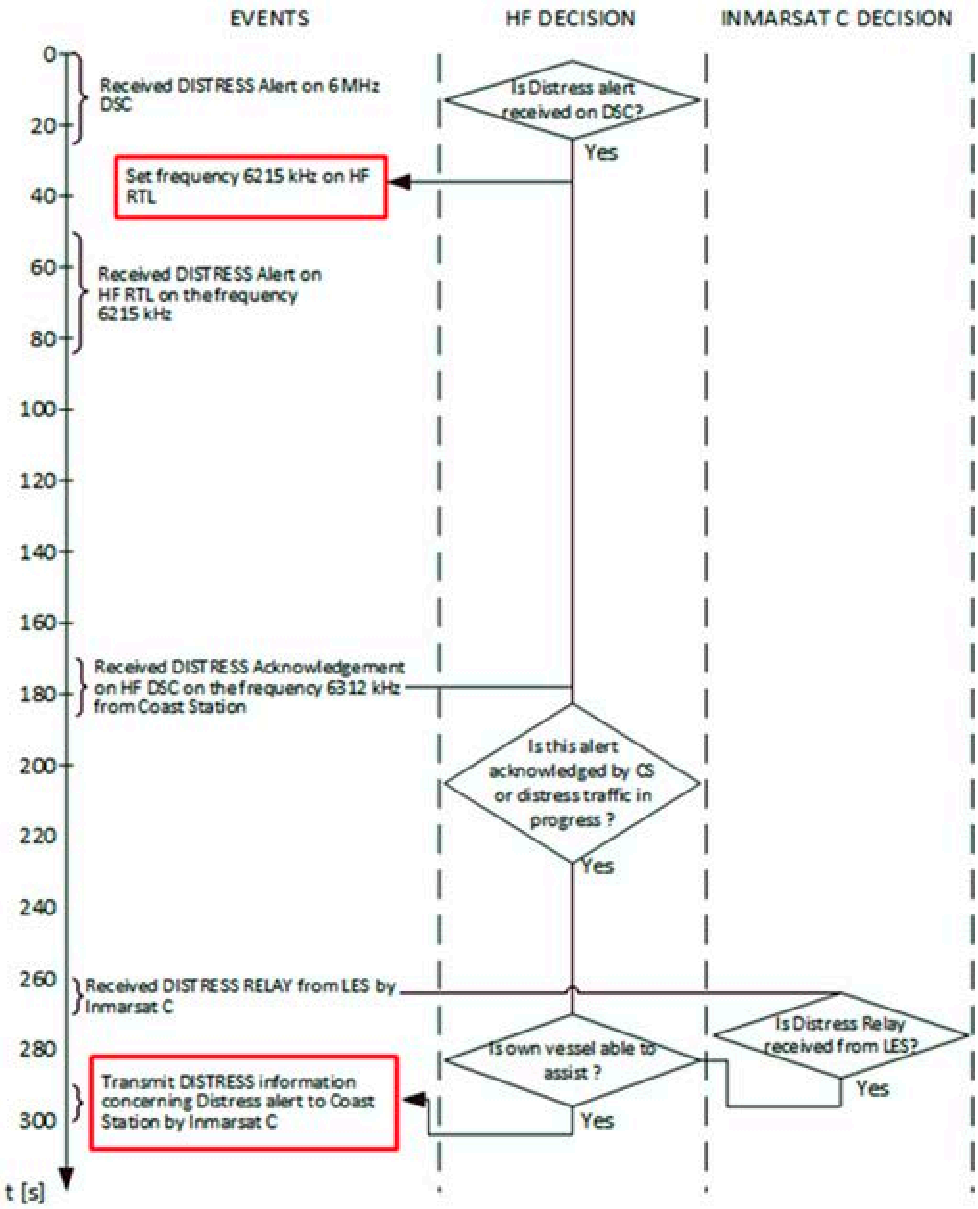

Figure 6. Event-decision diagram for ship S1 in the situation at 0000 local time

The boxes include selected events – actions directly performed by the radio operator on ship S1. The central part of the diagram includes the decision process for the HF band and Inmarsat C system. For better readability, the decision process does not show the whole procedure in case the reply was negative.

Based on the diagram and publications (Mąka, Lisaj & Majzner, 2014; Lisaj, Mąka & Majzner, 2015) we can note that the decision-making process for ship S1 is much simpler than if the alarm was picked up in the VHF and MF bands.

For ships S2 and S3 the decision-making process is also less complex, as these vessels, despite reception of the alert, are positioned at a distance that excludes effective assistance. The only required actions of the operators on these ships are reception of the message and making an entry in the radio log book.

Conclusions

This article presents a method of modelling allocation of communication events for the sea area A3. The following conclusions can be drawn from the above considerations:

- The proposed method of presenting a time diagram and the decision-making process makes it possible to display the flow of information between objects, in addition to the chronological visualization of actions already taken and those to be taken against the communication events.
- While determining the values of message availability matrix for sea area A3 we should consider many factors such as transmission power and radio wave propagation.
- The decisions to be made by the radio operator when an alert is received by more than one communication system is complex, and requires the equipment operator to be highly competent and proficient in its use.
- The proposed model reveals the complexity of problems associated with modelling the information flow where the effectiveness of certain means of communication depends on the time-of-day.
- It is necessary in the decision-making process to take into account the fact that some messages relating to the same event are doubled as they are received from various GMDSS subsystems.

These conclusions confirm the need to facilitate operators' work by developing a decision support system that would be an integral part of the Radiocommunication Events Management System.

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