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RADIO LINK SYSTEM SOLUTIONS FOR MOBILE PLATFORMS OPERATING IN SEA ENVIRONMENT

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ABSTRACT

In this paper radio link system solutions operating in 300 MHz — 3000 MHz range and sea environment were described. Solutions with more than one frequency and wave propagation models for horizontal not more than 50 km and far range were described. In the paper the results of actions taken design and construction solutions adopted were presented, aimed to contribute to ensure the reliability of the system, among other things, by implementing mechanisms for collecting and processing information. This solutions allow resources management to automatically adjust the transmission parameters configuration to the bitrate and range requirements. Available configurations can be extended with active part and electronic beam steering with one or more beams. The paper describes antenna systems ability of transmission parameters adaptation to get the range required.

Key words:

radio link budget, marine radio communication, wave propagation model at sea environment, antenna array, phase-shift beam control, sectorization, safety at sea.

Research article

INTRODUCTION

Maritime radio system solutions designed for special purposes are insufficient to meet growing needs, especially in the field of data transmission, allowing the provision of remote functionality. A high data transfer rate is required while at the same time fulfilling the ever-wider range of the radio link. The article presents solutions for distances up to 50 km with the purpose of using the system in the waterside and coastal so-called zone A1 [3] and ranges far above 50 km.

One of the many solutions ensuring connectivity in this zone is the use of land infrastructure of cellular systems [1]. The achieved ranges of around 40 km in quality measurement stations are insufficient. It is possible to increase the range by a minimum of 10 km, while maintaining the stability of the connection and quality parameters of the radio link, by using a ship-ship communication mechanism [2].

Another solution for communication between vessels, as well as communication between ships and infrastructure, is a standard developed by the IEEE 802.11p organization. It is an extension of the 802.11 standard (Wi-Fi), dedicated to intelligent transport systems [4]. As far as the bandwidths of the defined communication channels correspond to the requirements, the operating range 5855 MHz to 5925 MHz is no longer due to the limited range of operation.

Typically, the Polish USV submersible platforms have an operating range of up to 20 km [5]. Components of this type of unmanned vehicles are navigation systems, position tracking, remote control, observation system, chemical and meteorological sensors. A communication system is used to exchange data between the command center and the unmanned platform. Due to the limited scope as well as the surveillance horizon, single USV or swarms operating close to the supervisory unit are used. For UUV submarines, the surface waterway is a communication node as a station for data retransmission from a shore or onboard command center. Increasing the range of remote control is possible thanks to the use of surface and flying platforms. The UAS can be used as a retranslation station for the USV. Depending on the solution, it may be a UAS with limited autonomy moving at some distance from the USV or a multirotor tether (virtual mast). The complexity of the mission of unmanned platforms depends on their autonomy and communication with them, especially data transfer.

The requirements set by the user for communication with unmanned marine platforms go beyond the hardware capabilities of commercially available devices. Additionally, the need to achieve a high degree of reliability generates the need to implement a configuration change in order to ensure full functionality at the same time. To meet these requirements, it was necessary to design a dedicated radiocommunication system, whose organization is shown in fig. 1, built based on various designs of directional antennas (including sector one) and antenna systems with the ability to automatically adjust their configuration to changing environmental conditions.

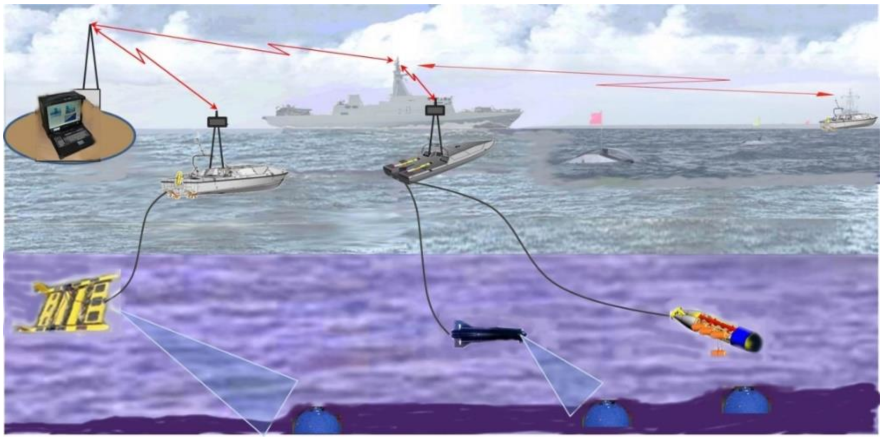

Fig. 1. Organization of communication for vessels and autonomous platforms

Different mechanisms have been implemented in the system depending on the source of the acquired location information, both the autonomous sea platform and the ship or shore station. The proposed system solutions meet the requirements set unmanned surface vessels and underwater platforms 'Kormoran II' and 'Guarana' and SDR architecture such as flexibility, interoperability, scalability and reliability, as well as cognitive radio (adaptability).

SYSTEM REQUIREMENTS

In order to meet the user's requirements, system solutions have been proposed, including:

- 1 Mb/s transmission speed and 5 MHz bandwidth;
- 10 Mb/s transmission speed and 10 MHz bandwidth.

A dedicated radio communication system enables data transmission with transmission speeds of up to 10 Mb/s using a radio channel with a bandwidth of 10 MHz at frequencies of 2.45 GHz.

To estimate the theoretical scope of the proposed system, the direct visibility of both radiocommunication link antennas was assumed. The maximum theoretical range resulting from the optical horizon is defined by the formula:

$$d_o = 3,57\ (\sqrt{h_1} + \sqrt{h_2}), \tag{1}$$

where:
d_o — optical horizon;
h — the height of the antenna.

To determine the radio horizon, the phenomenon of refraction in the normal atmosphere was taken into account, increasing the calculated value by 15%.

The installation height of the edge station antennas is assumed to be 50 m, while the antennas located on vessels at the height of 5 m or 20 m. For such assumptions, the range of the system is:
- 27 km for h_1 = 20 m and h_2 = 5 m;
- 38 km for h_1 = 50 m and h_2 = 5 m;
- 47 km for h_1 = 50 m and h_2 = 20 m.

From the radio link balance and from the fact that the USV navigational platforms have an operating range of up to 20 km, it is clear that the use of antennas with omni-directional character and 10 dBi gain is sufficient to meet the requirements. But in order to achieve the expected ranges by implementing system solutions, including an antenna system with the possibility of beam control and shaping a characteristic with a possible gain of 20 dBi to set up a mobile radio link (floating platform — shore/floating station), the following assumptions were made:
- transmission speed — min. 10 Mb/s;
- channel bandwidth — min. 10 MHz;
- range — min. 30 km.

In order to determine the radio horizon in the far zone over 50 km, the installation height of antennas resulting from the possibility of using a virtual mast was assumed:
- 70 km for h_1 = 50 m and h_2 = 100 m;
- 82 km for h_1 = 100 m and h_2 = 100 m;
- 91 km for h_1 = 150 m and h_2 = 100 m.

Obtaining such large ranges, however, is limited by the need to use 30 dBi antennas and increase the power of the transmitted signal, and more energy supplied to a dedicated system for mobile platforms.

ANTENNAS

In order to develop a dedicated radio communication system, it was possible to analyze the use of mobile antennas and antenna systems (arrays) on the UHF frequency range on mobile marine and land platforms. To meet the ranging requirements, and at the same time to ensure work in any direction (the possibility of any change of direction of the unmanned sea platform), a commercial solution of a 13 dBi omni-directional antenna with two orthogonal linear polarizations was chosen for reference to the design of dedicated antennas. Such a large profit and arrangement of radiators in one row translates into a small width of the beam in the elevation, which is less than 8°. As far as it is advantageous in the case of a radio link set in the chosen direction, in order to ensure communication with the mobile platform, it is not acceptable because during operation, the unmanned marine vehicle is subjected to heels, depending on the condition of the sea. Under typical operating conditions, tilt is assumed to be 15° for a ship and 30° for a small seagoing platform, and in extreme conditions, 25° and 45°, respectively. The consequence of using the antenna with a narrow beam would be the signal loss at long distances, especially at the range of the range resulting from the change in the signal power level by a dozen or so dB (typically 13–16 dB).

The compromise solution is to use a sector antenna with increased values of key parameters, i.e. a higher gain of 16 dBi and no less beam width in the facade relative to the omni-directional antenna or antenna with a larger beam width, but with the same gain. As a consequence of the division into sectors and the smaller beam width in the azimuth of 90°, however, there is a reduction in the power level radiated in the system of 4 connected sectors. The advantage is the ability to switch sectors depending on the direction on which the sea platform operates. Due to the construction of the aerial mast of the ship, a sectoral cylindrical antenna was built. The cross-section of the structure is a ring to allow the antenna to be mounted directly to the mast.

The development of a dedicated antenna system using beam control [7] allowed to obtain simultaneously the parameters of directional antennas (angular width of radiation and maximum energy gain in a selected direction with narrow main beam and low level of side lobes) and omnidirectional. Arrangements built with antenna arrays allow both to shape the beam in a specific direction, as well as to control its position in space, and also to quickly change the direction of maximum radiation. Due to the possibility of dividing each sector into 5 configuration variants in a horizontal plane every 20°, 4 sectors were the optimal choice as for the cylindrical sector antenna. To ensure an even beam width (connection of two sections), two variants are planned in both planes of 20° — angles of beam inclination, i.e. –10° and 10°.

Both the cylindrical sector antenna and the antenna system were designed using the CST software. The system was built from the formation of 2 rows of 4 dipoles, and the power supply was supplied by coaxial cables directly from the phase shifter outputs to which the signal was supplied from the 1: 2 dividers. Pairs of dipoles have been combined to form blocks of 4: 2 or 2: 2 as well as 4: 4 in a system extended by the second section. The smallest block allows to gain a 13 dBi gain in the system with the possibility of increasing with a step of 3 dB. The profit of the designed antenna system is 17.4 dBi, while the width of the main beam in azimuth is 19° and in the elevation of 36°. The beam control was implemented by changing the phase delay of the signals at the dipole inputs, i.e. by using two types of circuits. In the first phase change was implemented by changing the settings of switches in combination with delay lines, while in the second system by changing the input voltage of phase shifters. The values of phase shifts for individual radiators have been selected so that they correspond to angle shifts of –40°, –20°, 0°, 20° and 40°. Additionally, to achieve the inclination, the progressive phase shift of the power phase was realized. For two sections and an angle of 10° it is 46° and for an angle of 15° it is 68°, while for one section and an angle of 10° it is 58° and for an angle of 15° is 84°. In order to minimize the suppression of the lateral lobes, a suitable distribution of amplitudes (Taylor) of excitation signals has been applied.

SYSTEM SOLUTIONS

Based on a cylindrical sector antenna on one side (autonomous platform) and an antenna system with beam control on the other (floating platform — shore /floating station), it is possible to build a communication system for mobile offshore platforms meeting the assumptions. In addition, due to the possibility of changing the configuration of the antenna system, two frequency ranges have been integrated into the system with two orthogonal polarizations (the functionality of the MIMO 2 x 2 mode).

Due to the need to develop an efficient, as simple as possible integrated resource management mechanism [6], and at the same time a solution of the antenna system meeting the normative requirements of DN3 class directional antennas constituting the system section was adopted. For simplicity, the method of feeding the antenna system works in one frequency range in both polarizations. For both ranges and both polarizations, the number of both phase shifters and power amplifiers (stages I and II) and LNA increases to 32 (two rows of 4 radiators for 2 frequency ranges and 2 polarizations).

The signal level (or two for both polarities) at the input of the beam forming system is 20 dBm, i.e. the maximum allowable level for unlicensed bands. However, for two ranges of frequencies 1.3–1.4 GHz and 2.2–2.3 GHz in the antenna arrangement, the possibility of power equalization up to the level of 20 dBm at the radiators input was designed. Leveling takes into account both the distribution of power supplied to all radiators, as well as losses in the phase shifter and diplexer path, and allows the formation of a beam with a power of 30 dBm. In the system it is also possible to increase the power to a maximum of 33 dBm at the input of each radiator, which allows you to form a beam with a power of 40 dBm for each of the ranges and both polarizations.

Profit in the system is at least 17 dBi and can be increased by combining 2 or 4 sections in the same sector (in the vertical plane) by 3 or 6 dB. The combination of sections in the horizontal plane allows for the construction of 4 sectors of the omni-directional antenna system shown in fig. 2. The proposed solution allows for beam control both in the horizontal plane in the range of angles of ± 45° and in the vertical plane in the range of ± 15°, allows to ensure, taking into account the maximum tilts of the ship, the signal power of ± 3 dB in the range of 360° in azimuth, and 70° in the elevation for a single section and 50° for two sections of the antenna system. In the future, it is planned to expand the antenna system in order to increase the range of the beam angle in the facade, taking into account the larger tilts of autonomous small sea platforms at the sea state 5, as well as ensuring adequate signal strength in a larger range of elevation angles for more sections. The construction of a cylindrical antenna system with beam control is also planned.

The use of a omni-directional antenna system makes it possible to carry out unreliable transmission at 10 Mb/s for a minimum distance of 30 km for a low power of 20 dBm. A fully equipped antenna system allows to increase the range up to 50 km and 30 dBm signal power, but on condition that the system has a sufficient mounting height on the mast. The minimum heights are respectively:
- 40 m on both sides of the radio link;
- 20 m on one side of the connection (vessel), 60 m on the other side;
- 5 m mast of the unmanned sea platform, 100 m coast station.

Fig. 2. The combination 4 sections of antenna system model

Getting the right heights is often impossible. One of the desirable solutions, especially in communication with unmanned platforms, is a virtual mast (platform of, among others, observation sensors) allowing for a height increase of 100 m. It will be particularly advantageous to increase the antenna suspension height at coastal stations acting as repeaters up to 100 m. It is not technically possible to extend the range beyond the horizon by increasing the height of the antenna system, so it is necessary to use tropospheric communication, for which it is possible to form a beam with a power of up to 40 dBm in the antenna system.

Due to dynamically changing environmental conditions, the measurement of the parameters of the antenna system is carried out continuously. For this purpose, information is collected and appropriately processed taking into account incidents of inconsistent information (uncertainty and incompleteness of sensory information). If the required range of any of the parameters is exceeded, an analysis of the possibility of meeting the requirements in other system configurations is made. Limiting the dynamics of changes in the level of the input signal from the low signal power side is the level of noise, while despite the appropriate level of signal power it is possible to disturb it by an adjacent transmitter or higher power level received signal e.g. above 60 dB (too low selectivity) so it becomes necessary to apply additional filtration or increase the interval between frequency bands allocated for different channels. Regardless of the frequency range of the work, the goal is to ensure that the parameters are not deteriorated (maximum power in transmission without distortion, full dynamics in reception, selectivity assured) when working in collocation (many channels at the same time).

Beam control provides increased range while reducing the level of radiated and received noise. The antenna system also allows for better use of resources through fast automatic change of configuration of used modules to adapt to current functional and operational needs such as the expected range. It is possible to adapt the configuration to the variable distance of the mobile object from the base station. In order to determine the minimum level of power transmitted to the expected range in the system, various mechanisms are implemented depending on the source of the acquired location information, both the autonomous sea platform, and the ship or shore station.

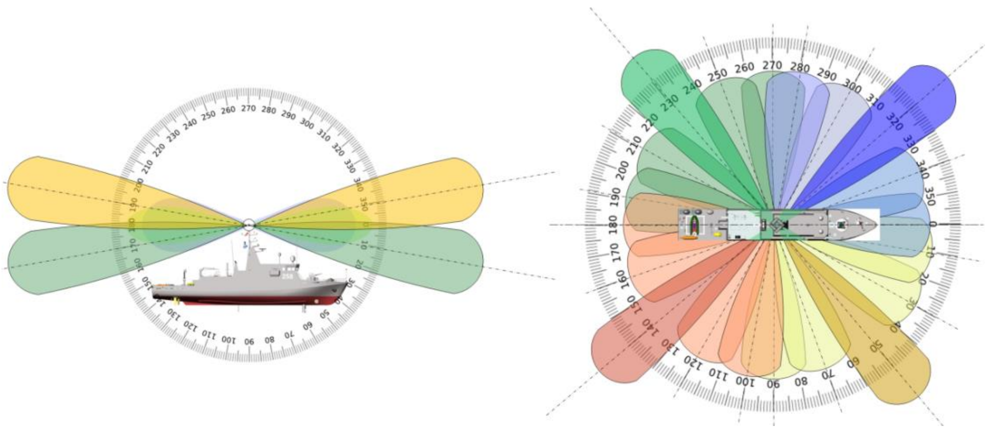

Fig. 3. Characteristics of the adaptive radiation of the antenna system

For example, if GPS coordinates of the location of both objects are available in the system, time signal and data from miniature gyro-compasses that use the principle of fixed position in the rotation axis of the spinning bit, it is possible to set the appropriate antenna configuration in the expected direction with acceptable accuracy (constant error with sensors are easy to correct). Further direction maintenance is carried out by scanning adjacent configurations every 20° and changes when the signal power level is higher than in the work configuration (required feedback from the receiver) as shown in fig. 3. In the event that there is a temporary lack of GPS information or In the memory of gyro-compass, the last acquired location data is saved. Due to the use of two stages of power amplifiers in the system, it is also possible to adjust the signal power transmitted to the expected range.

The external sources of information are facilitated by the beam control mechanisms, but they do not replace them, therefore in the situation of lack of availability also when starting the antenna system there is the possibility of fully adaptive configuration adaptation. To this end, it is planned to use inertial navigation, which is based on the measurement of accelerations in two or three directions and determination of displacements relative to the starting point. The measurement will take place in a system of accelerometers stabilized by a gyroscope system. The methods used in the radar technique will also be used, for example, the mono-pulse method that allows automatic tracking of the target.

The reliability model for the antenna system has been developed on the basis of ensuring the functionality that is most important from the point of view of the potential user, including the system's readiness for work. There are many potential configurations of the radio system, not all of which are realizable. In order to enable making a decision regarding the selection of a feasible configuration, optimal from the point of view of reliability, as well as utility and losses in the antenna system, a mechanism for assessing individual configurations was proposed, taking into account:
- reliability of the configuration, determined on the basis of the reliability (physical failure) of its components and the time of repair;
- usability of the configuration (potential usable capabilities), e.g. minimum radio range;
- losses in the antenna system, e.g. maximum range.

The reliability assessment model takes into account such configuration features as:
- operating mode: transmission/reception;
- type (transmission or reception): active/passive;
- design (space in the amplifier system): internal/external.

The physical failure of the configuration is a parameter that determines the degree of compliance of the configuration to the physical damage of its elements. For obvious reasons, physical efficiency depends directly on the number of configuration components. 'Rational coverage', on the other hand, is a parameter independent of the physical failure rate and configuration repair time.

CONCLUSIONS

The various system solutions presented allow for the implementation of resource management that allows automatic adjustment of the configuration to the current needs of the user regarding primarily the expected range and bitrate, as well as energy savings and trouble-free operation. For this purpose, information is collected and processed appropriately using the data fusion subsystem. Optimization consists in determining a compromise area that takes into account parameter tolerances for the failure-free operation of the antenna system and the expected range. The built-in self-monitoring mechanism ensures that the requirements contained in reliability programs are met.

Various system configurations are possible depending on the direction of the beam in space and its transmitted power adjusted to the expected range, as well as in order to achieve the required dynamics of the antenna system, and hence the efficiency of work. Profit of a single system section is 17 dBi and can be increased to a maximum of 23 dBi by combining two or four sections (scalability) in the sector. The antenna system allows obtaining a horizontal range in the established radiocommunication link in spite of the low transmission power of up to 30 dBm.

In the dedicated radiocommunication system for mobile offshore platforms, an algorithm of adaptive adjustment of system parameters to a variable environment and thus an appropriate change in the configuration of the system's operation was applied. Integrated in the system were radiators that allow working in two frequency ranges and two polarizations, which allowed to increase both the bandwidth in the broadband channel and reliability. Several different techniques were used in the implementation of the antenna system, including a beam-controlled system using mechanisms of its stabilization in the expected direction, both in the chosen sector (work in collocation) and in the field.

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ROZWIĄZANIA SYSTEMOWE ŁĄCZY RADIOWYCH DLA PLATFORM MOBILNYCH OPERUJĄCYCH W ŚRODOWISKU MORSKIM

STRESZCZENIE

W artykule przedstawiono rozwiązania systemowe mobilnych łączy radiowych pracujących w zakresie częstotliwości 300 MHz — 3000 MHz w środowisku morskim. Zaprezentowano rozwiązania dla wybranych częstotliwości z uwzględnieniem modeli propagacyjnych sygnałów dla zasięgów horyzontalnych do 50 km oraz dalekich. Przedstawiono szereg działań projektowych oraz przyjętych rozwiązań konstrukcyjnych zapewniających niezawodność systemu, między innymi mechanizm zbierania i przetwarzania informacji. Rozwiązania te pozwalają na zarządzanie zasobami w sposób automatyczny oraz w pewnym zakresie autonomiczny, dostosowując konfigurację parametrów transmisyjnych do aktualnych wymagań na przepływność i zasięg. Konfiguracje mogą zostać rozszerzone między innymi o część aktywną oraz sterowanie jedną lub kilkoma wiązkami.

Słowa kluczowe:
bilans łącza radiowego, radiokomunikacja morska, model propagacyjny fali w warunkach morskich, szyk antenowy, sterowanie wiązką, sektoryzacja, bezpieczeństwo na morzu.

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