MULTISTATIC SYSTEMS

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This paper describes key features of a multistatic operation in the littoral beginning from multistatic system (MS) configuration, his performance model and constraints imposed by environment of shallow water. The architecture of MS, features and requirements of MS basic subsystem has been presented. Essential role as during MS operation is fulfilled by data fusion and tracking methods as well a communication between MS units, has been protruded. The application of MS, especially for underwater protection systems, in the form of barriers protecting anchorage, harbour, straits or entries to the harbour has been presented. Other applications are connected with military operation, especially Anti–Submarine Warfare (ASW) in littoral areas. Attention was paid on possibility of cooperation among the different acoustics devices in MS.

INTRODUCTION

General the MS system can be build as a processor feeding directly from existing equipment designed for monostatic operation plus data fusion system for additional processing–presentation.

Multistatic system where one source is used to provide acoustic energy for a number of receivers is an example of system where improved overall performance may be achievable under the emission of acoustic energy minimization (sea environment protection and protection of marine mammals).

Showed below Fig. 1, illustrates operation of transmitting and receiving devices in the multistatic system. Left figure shows a simple MS configuration: one transmitter (i.e. sonar) and two receivers (i.e. sonars, sonobuoys, receiving acoustic modules). Right figure displays surface coverage of the system for fixed positions of acoustic devices and pulse parameters. The ranges (detection and dead zone) have an ellipse shape. It is clear that this configuration may compose from three sonars operates independently, but due to their connection in one multistatic system, significantly increases the probability of target detection and localization as well as coverage. The same result may be obtained using specialized acoustic modules – cheaper and simplifier than sonar.

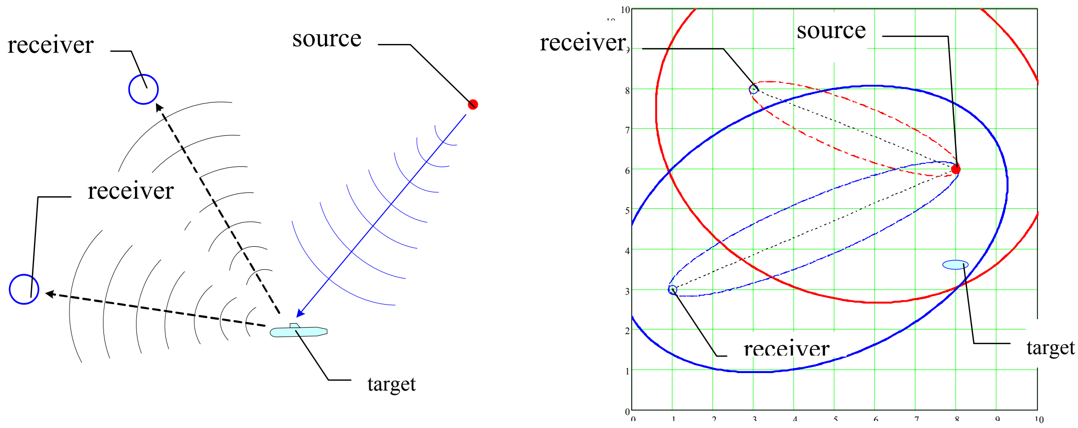

Fig.1 Multistatic system: left – system configuration, right: coverage for determined source parameters and sensors position – solid line – detection range; dotted line – dead zone

Acoustic propagation in shallow water (depth less than 200 m) is dominated by repeated interaction with boundaries channel – sea bottom and surface (Fig. 2). To the receiver arrive a set of acoustic signals consisting both target echoes and non–echoes. The signals arriving to receiver along each propagation path can contain target signal, surface, bottom and volume reverberations, environment noises and moreover each paths has "own" transmission loss. Multiple paths may be considered from two points of view – in high frequencies, for short signal (shorter than the mean delay between path arrivals) their effect is observable in the time domain as sequences of multiple echoes, instead in low frequencies the wave reflected from sea surface produces interference fringes creating a stable interference pattern with strong variations of signal amplitude. It is noted that in multistatic configuration forward and out–of–plane scattering are important unlike monostatic configuration when reverberations is due to backscatter. Above mentioned "contributions" in the received signals may be increased if in observed space/sector is a number of acoustic sources and targets as well as if propagation conditions are variable. It makes a serious challenge for designers of multistatic system especially within the scope of signal processing, compatibility of different devices and systems communication between the devices – the problem is detection of target signal against whole background noise, target localization and tracking.

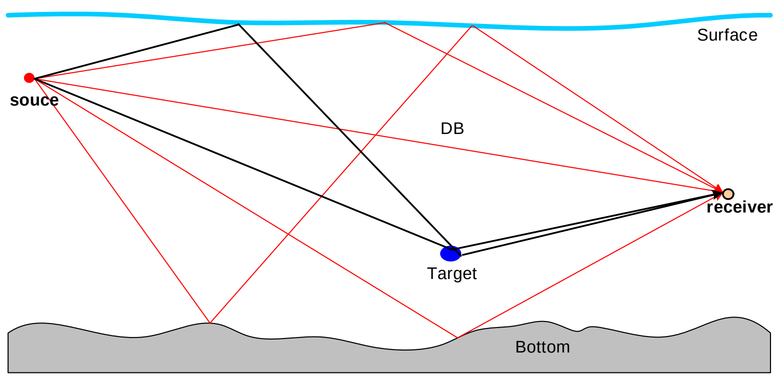

Fig.2 Multiple paths (DB – direct blast)

1. MULTISTATIC SYSTEM

1.1 MS performance model

MS may be treated as set of temporary mutually connected mono and bistatic configuration. Bistatic configuration is characterized by a triangle of source, target and receiver position – Fig. 3, and his performance may be expressed in the form of bistatic sonar equation (1) [2].

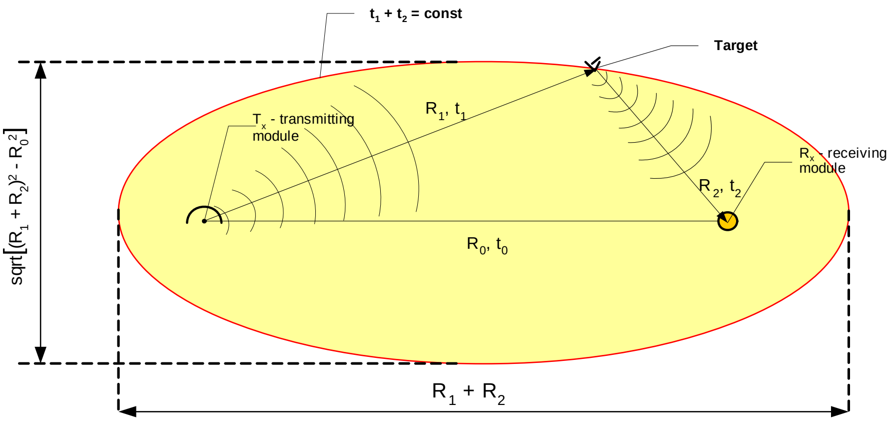

Fig.3 Bistatic geometry

$$SE = ESL - TL_1 - TL_2 - [(N_0 - AG_N) \oplus R_{SL}] + TS - DL \qquad (1)$$

where:

SE – signal excess,
ESL – energy source level = SL + $10\log_{10}T$; T is the duration of the transmitted pulse,
TL_1 – transmission loss from source to target
TL_2 – transmission loss from target to receiver
N_0 – noise spectral level
AG_N – array gain against noise
TS – target strength
DL – threshold required for detection
R_{SL} – reverberation spectral level
$\oplus$ – "power summation" defined as $\oplus = 10\log\sum_{i=1}^{n}10^{L_i/10}$, where L_i is the level of the *i* th noise source [dB] and *n* the number of contributing noise sources.

1.2 MS architecture

MS is the network of deployed acoustic devices containing signal sources, receivers, control and communication blocks as well as block determining temporary device position (i.e. GPS sensor). Acoustic devices that may be used are sonars, sonobuoys or specialized acoustic modules: transmitting or receiving. The network based on the ship's sonars, sono-buoys or sonars+sonobuoys are characteristic examples of MS. The architecture of MS based on sonars shows Fig. 4 – there are a general block diagram of the MS operating as stationary system – black and as mobile system – black + blue colour.

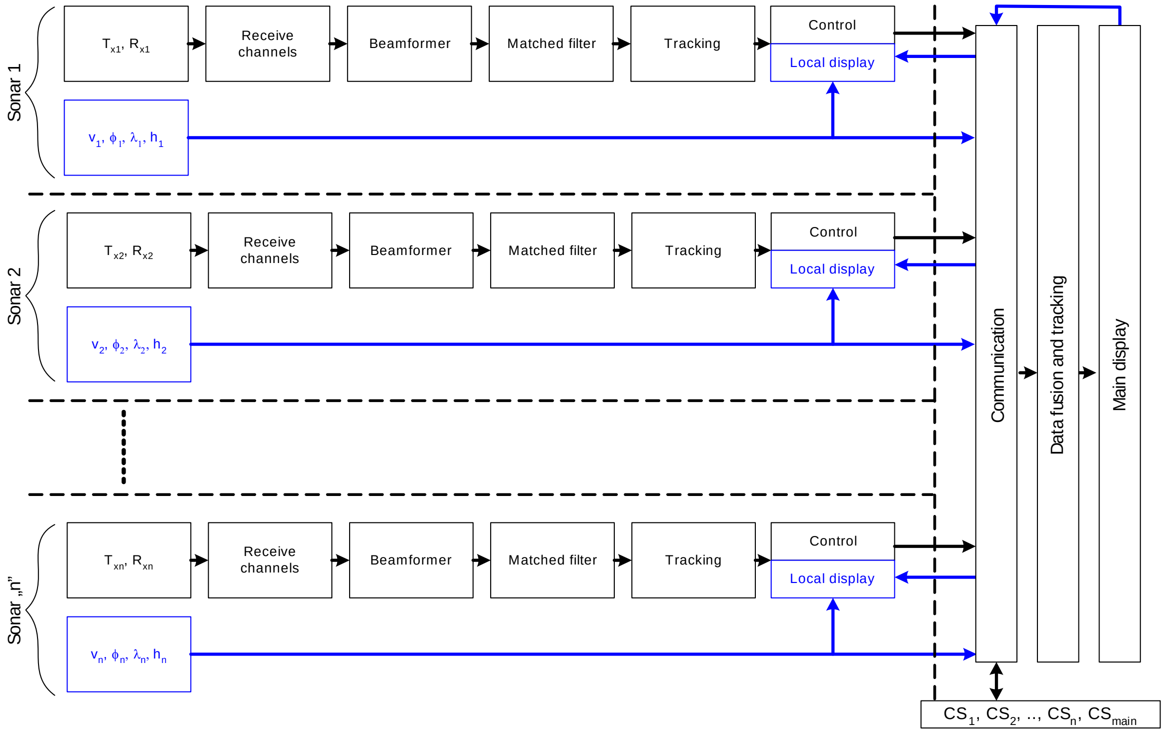

Fig.4 Block diagram of the MS system

1.3 Mutual interferences between sonars

Some of important disturbances in sonar operation are signals emitted by the other sonars. The sonars are received these signals by direct trace, as echoes from the targets or as reverberations. The mutual sonars interference level depends on many parameters, like: the transmitting modulation and bands aliasing, the distance and mutual localization of transmitting and receiving sonar's arrays. The mutual interferences between sonars can be particularly sharp for MS operation – when the similar type of sonars with the same frequency band is used in the same area. The analysis of such situation should be carried out for finding optimal solution of mutual interference reduction for selected modes of transmission control (defined three transmission policy – independent, sequential or coordinated). For sequential transmission once a ping is transmitted – full band and any type of modulation can be used. Independent transmission requires frequency separation or various type of modulation supported by changing pulses length. In the coordinated mode, the signal transmissions are controlled by main control centre.

1.4 Signal Processing

A demonstrative view of a network of deployed three acoustic devices (AD) is shown in Fig. 6. If assumed that each AD is the sonar or sonobouy than echoes from each ping are received and processed by each sonar/sonobouy. It means N^2 combinations source–receiver in the network of N acoustic devices. In Fig. 6, we have illustrated signal paths for 4 of 9 possible combinations.

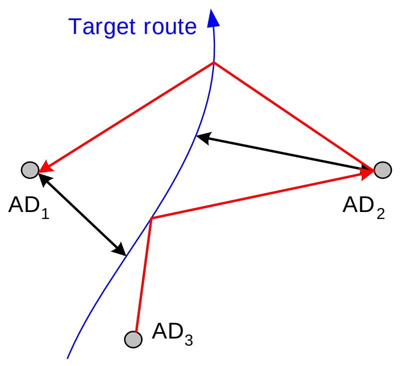

Fig.5 Network of deployed AD with bistatic (red) and monostatic (black) signal path

Received signals are subjected pre–processing (filtering, matched filtration, data formation), creates a set of contacts. The contact is triplet (source–ping–receiver) and set of contacts may be arranged basing on ping times. It is noted that each contact have an own observation time – the same time ping and the same target may responded a lot of observation times [3]. With communication links among the acoustic devices, all the sets of contacts are transferred to control centre where are subjected to data fusion and tracking.

The main processing (on the control centre) has the following two goals:

- acquire all transferred data,
- process this data all the way up to multistatic contact formation and geo–referenced positioning.

As noted in introduction, for unfavorable propagation condition, the direct echo signal may be interfered by secondary echoes results from signal reflection from sea surface and bottom as well by bottom and surface reverberation. This undesirable phenomenon may be, in great measure, cancelled by using of signals normalization in relation to background signals. The normalization method may be applied for MS system operating in stable propagation conditions – period of the stability should be not less than 6 ÷ 12 hours. The normalization procedure should be conducted every 6 h, unless in observation sector a great number of the false echoes has been appeared.

1.5 Data fusion and tracking

The data fusion engine is the core part which adds new functionality to current-day (monostatic) sonar systems. Five data fusion method are in use today: data association, positional estimation, identity fusion, pattern recognition and artificial intelligence. With each method the discrete data fusion technique can be identified. The first general method of data fusion that may be used in MS system is data association. This method correlates one set of sensor (sonar, sonobouy, acoustic module) observation with another set of observation. As a result of this process, data association is able to produce a set of "tracks" for a target. It is the initial step necessary for target localization; this may be later enhanced with the identification of other characteristics associated with the target. The input of the data fusion is contact files, containing the contacts identified by each of the source–ping–receiver triplets. A fundamental challenge with data association is make decision which observations should be combined into track estimates. In the past decade the techniques of data association and other data fusion methods has been widely developed and described in literature related to this i.e. [4], [5].

The main features data fusion of MS is:

- collate contact files,
- store all contacts in an archive database,
- handle both mono– and bistatic contacts,

– automatically select a proper subset from these contacts, if the unit does not manage to operate real-time,
– combine the information in the contact files,
– produce multistatic and monostatic tracks simultaneously for comparison.

1.6 Communication

The reliable communication between the particular MS system units (ships, sonobuoys, acoustic modules and sonars) and between the unit's components is an essential condition of the system proper operation. The communication system has three functions:

– external communication: forming a network between the units to allow secure and reliable data exchange,
– internal communications: forming a network between the various components of the one unit,
– provide a time reference (global time synchronisation signal) common to all units.

Within the MS system, the communication modules should be unified and fulfilled the following goals:

– encryption of the data for external communication
– automatic routing of data between processing stages
– provision of global time reference to local processing for time-stamping of data.

1.7 Human Computer Interface – display

The goal of the Human Computer Interface (HCI) is to provide the operators with the necessary graphical/numerical information to perform multistatic operations within a defined scenario. To fulfil this goal HCI are required the following main data:

– geographical maps,
– multistatic contacts and trucks,
– own (ship's, unit's) data.

On the basis of above mentioned data HCI should be as follows:

– to display the multistatic output,
– to provide a display of the network status and configuration,
– to record the display output.

2. MS APPLICATION

2.1 Multistatic for Low Frequency Active Sonar

NATO has established project for multistatics. The objective for this project is to demonstrate an improved and more effective undersea surveillance ASW capability in littoral waters [1], compared to current techniques, by using multistatic Low Frequency Active Sonars. The multistatic project has arisen from multistatic research conducted by nations and the NATO Undersea Research Center (NURC). Within NATO is recommended networked Low Frequency Active Sonar (LFAS), sonobuoys, bottom mounted sensors operating multistatically as promising concept for long term collaborative development. The development of the multistatic concept is expected to lead to research and experimentation areas such as: link

– communication standards, data fusion techniques, models sonar–environment, operational research.

2.2 Anchorage/harbour protection

Anchorage, especially naval ships, as a high value asset creates a potential target of terrorist attack. To protect the anchorage, acoustic barrier may be composed with bistatic (BS) segments (segment contains transmitting module and receiving module), receiving module (R_x) and sonar (R_x and DDS sonar are formed BS segment). Example of this solution is shown in Fig. 6.

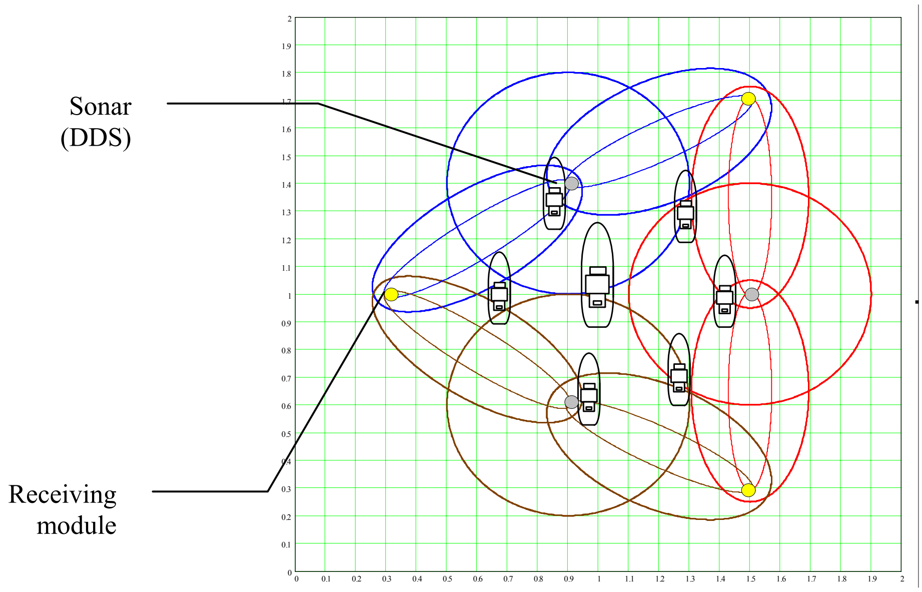

Fig.6 Anchorage protection. The barrier creates three sonars (DDS) and three receiving modules. Protected area is approx. 1.5 km^2. Thick line – detection range, thin line – dead zone. DDS range is 400 m

The same solution as anchorage protection may be applied to harbour protection – the barrier configuration should be matched to harbour configuration – Fig. 7. The observation sector of the DDS is 360^0 – it is most advantageous solution enabling a full coverage of the anchorage. DDS with 180^0 observation sector is also possible, but in this case the barrier will protect only the areas enclosure of anchorage – anchorage interior will not be protected. Fig. 7 is an example of entire harbour protection consisting surface (radar, TV, FLIR) and underwater (acoustic and magnetic) protection. MS acoustic barriers presented in Fig. 7 creates two protection zones: second zone in form of barrier composed by acoustic devices (sonar, sonobouy or acoustic module) and third zone composed by sonars with range up to 600 m and $360^0/180^0$ observation sector. The third protection zone may be also composed by specialized acoustic modules. All protection means are managed by land–based control centre.

Barriers configuration, these from Figs. 6 and 7, depends on size and shape of the protected area, sea area configuration (depth, sea floor slope, underwater obstacles), acoustic devices parameters (source level, pulse length, time duration, type of modulation) processing gain of the receiver and predicted propagation conditions. On the basis those input data, the barrier configuration (number of acoustic modules, their position and pulse parameters) should be established.

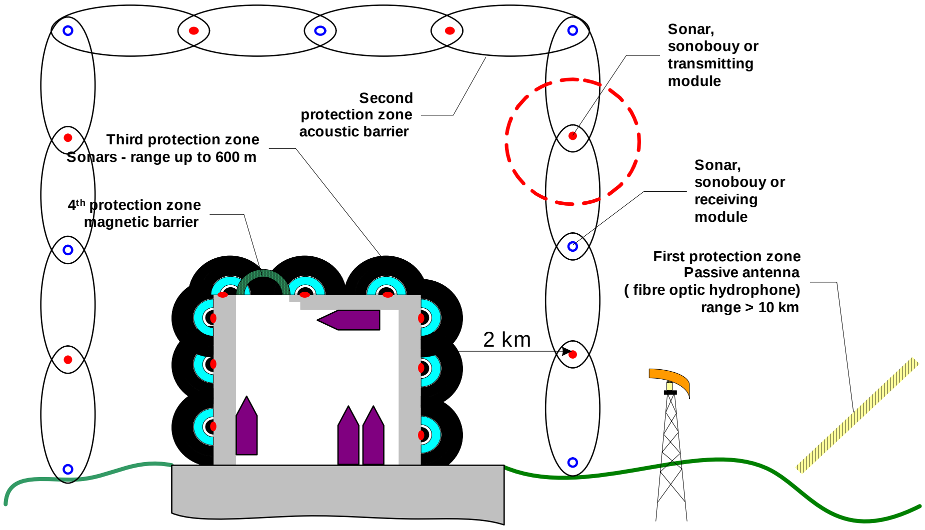

Fig.7 Harbour protection system for surface and underwater protection

3. CONCLUSION

1. The multistatic system has a significantly advantages in comparison of monostatic system:
   - localization and target classification is easier and more reliable due to more then one receiver detect the target,
   - observation sector is extended,

but simultaneously requires:
   - reliable communication system between the system elements,
   - settled devices parameters,

sophisticated processing method.

2. The usage of multistatic technique enables designing and building an effective acoustic systems protected high value assets.

3. The protection system may be designed as barriers composed of sonars, sonobuoys or specialized acoustic modules.

4. The barriers composed of specialized acoustic modules has the same effectiveness as barrier composed of sonars but are significantly cheap.

REFERENCES

[1] J.E. Halen, D. A. Frederick, M. G. Ogle, Effectiveness of Dipping Sonar and Sonobuoy Multi–Static System in Establishing and Maintaining Littoral Barriers, UDT Europe 2003, Malmo, Sweden,

[2] P. C. Etter, Underwater Acoustic Modeling and Simulation, Spon Press, London, 2003,

[3] S. Coraluppi, D. Grimetti, Intra–Ping Timing Issues in Multistatic Sonar Tracking, 7th International Conference on Information Fusion, 2004, Stockholm, Sweden,

[4] D.Hall, Handbook on Data Fusion, CRC Press, June 2001,

[5] R. T. Antony, Principles of Data Fusion Automation, Artech House, Norwood, Massachusetts, 1995.