REVIEW OF THE DOCTORAL (PhD) DISSERTATION

NATIONAL UNIVERSITY OF PUBLIC SERVICE
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CHALLENGES AND SOLUTIONS FOR STRATEGIC DATA COLLECTION FOR NATIONAL SECURITY PURPOSES IN MODERN SHORTWAVE TELECOMMUNICATIONS SYSTEMS

author's review of PhD thesis

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THE DESCRIPTION OF THE SCIENTIFIC PROBLEM

Based on an extensive study of the scientific literature, I have concluded that the use of the shortwave band for communication has been revalued in the 21st century, which has not left the new challenges of data acquisition for national security purposes untouched.

In the theoretical research of spatial diversity reception, many scientific achievements have been made. These in particular cover the development of wave propagation models, the application of code simulation methods, source processing methodology and channel simulation methods.

However, none of the sources studied has provided a methodology for the professional comparison and analysis of practical measurement results.

The specific environment of strategic data acquisition systems poses new requirements, in which the search for multi-sensor reception opens up new challenges.

Data mining for national security purposes has a long history as an information gathering activity. As new, more advanced modes of communication have emerged in radio communications over the decades, the requirements for intercepting and understanding the content of communications transmitted over radio frequency transmission channels became on newer and newer transmission techniques. The general evolution of radio communications in the 20th century (analogue information transmission, digitisation, electron tubes, semiconductor devices, use of lower frequency bands, higher ranges, increasing number of links) has also presented a continuous challenge for the intelligence organisations in terms of establishing new data acquisition capabilities.

It was neither different from the point of the need for development of radio monitoring capabilities in the shortwave range. In particular, the HF frequency range moved up on the priority list during the Cold War period following World War II. By the 1960s and 1970s, the two great adversaries were engaged in operating a network of agents covering virtually the entire World and, of course, were interested in the reconnaissance of the adversary, and therefore devoted socially significant resources to this activity.

The period of changing the regime in the socialist countries was still largely dominated by the operation of radiomonitoring technology in the form of a receiver fleet of electron tube (single-channel, single-operator hand-tuned discrete receivers, possibly organised into a few individual receiver groups with a single operator) types.

By this time, the need to monitor an increased number of simultaneous radio channels had filled entire halls with a mass of receivers (and operating personnel). In this structure, the elements of the data acquisition process were separated in space and time, with reconnaissance, signal recording, direction finding and locating, technical analysis and offline signal analysis all taking place separately.

The change of regime brought a major change in two environmental conditions. On the one hand, the end of Cold War tensions reduced the importance of the short-wave spectrum, while at the same time the period coincided with the final supremacy of semiconductor technology over electron tubes.

However, after decades of 'dormancy', the first decades of the 21st century faced the return of HF band data acquisition to its former importance, but with a new role in terms of technical and technological content. The new types of digital transmission and the increased magnitude of simultaneous transmissions could no longer be controlled based on individual discrete receivers. Increased transmission capacities, the growing number of communications networks and changes in customer requirements have individually, and collectively, dramatically changed the quantitative and qualitative requirements for data acquisition for National Security purposes.

The proliferation of SDR software-defined radio and broadband reception technologies and the content enrichment of the bandwidth for new types of services have paved the way for a higher level of demand for data gathering at strategic levels.

New technical requirements have also emerged in relation to strategic systems, such as:

- continuous full band recording of the entire bandwidth;
- the ability to process a large number of signal sources simultaneously;
- super-sensitive reception capabilities;
- high sensitivity direction finding and location;
- complex channel management methods;
- automatic source detection;
- automatic signal classification and modulation detection;
- automatic code recognition;
- automatic speech, language and speaker recognition;
- advanced automatic technical analysis;
- automatic cryptoanalysis;
- pattern-based signal recognition;
- extensive analysis capabilities.

From above, the requirements for reception capabilities and direction finding accuracy are the critical requirement factors on the reception side of the system, at the front-end elements.
Strategic systems, therefore, require a different approach to development, design and operation.
It is therefore legitimate to raise the question of how the already unique characteristics of the shortwave band (wave propagation characteristics, band anomalies, congested frequency allocation) affect the performance of data acquisition tasks in the band. To answer this question, two different sets of criteria need to be considered.
On the one hand, new broadband front-end units are organised along architectures that incorporate SDR software radio adaptations. These platforms can ensure the capture of high-volume messages.

However, strategic data acquisition systems may have more than one customer unit. In this case, the question arises as to how messages that are generated separately in space and time - of different quality but identically - can be combined in a way that the resulting record has better quality characteristics than the individual records.
A further problem is a fact that in strategic systems, due to the broadband nature of the recording, the coupling of individual message pairs offline may be time-shifted.
Methodological consideration is also needed to decide at which level of information the sharing of acquired records should take place. In the case of digital transmissions, messages may be merged based on bits, symbols, word groups or code line units.
As a quality attribute of digital modem communication messages, the quantitative availability of decoded content is essentially the determining factor, i.e. the percentage value that indicates how much of the actual message content contains successfully demodulated and decoded information.

The trend outlined above poses a multifaceted challenge to agencies that collect data for national security purposes.
On the one hand, meeting the increased user needs should enable them to obtain large amounts of information, allowing them to perform their tasks with a higher degree of efficiency. This can be measured in terms of the quantitative characteristics of the extended capabilities (number of messages received, length of acquisition/communication production time, number of channels that can be processed simultaneously, etc.) or in terms of qualitative indicators (improvement of some quality

indicator of the received telegrams/communications). The indicators above can currently be achieved using available receiver equipment and technical technologies.

At the same time, **there is currently no** developed method or recommendation **for improving the quality indicators** of the acquired communications and for objectively assessing their characteristics. **A particular aspect of the solution to this issue is that the missing quality improvement process must necessarily meet the criteria of automatability and be adaptable at a system level in strategic data acquisition systems.**

As the main guiding principle of my research, I have set the niche objective to investigate how multi-sensor, diversity-based quality enhancement of shortwave bandwidth offline recorded communications can be effectively characterized along real values, and what procedure can be developed to characterize the effectiveness of the diversity reception method as diversely as possible on the basis of practical values.

Based on this, the main elements of my research study are structured sequentially as follows:

- - As a preliminary option, I would study the shortwave band through a comprehensive and analytical review of the national and international scientific literature.
- - Using simulations, I would investigate the theoretical effectiveness of diversity signal combining methods based on channel characteristics.
- - I would seek answers to the question of whether Hungary is suitable to operate an efficient multi-sensor diversity reception capability in the shortwave band
- - I would execute practical diversity measurements, the results of which are not available so far, and analyse the practical effectiveness of the signal combination methods, the capabilities of receiver diversity test and evaluation methods based on data analysis, and the possibilities for further development.
- - Based on the results obtained, I would develop an analysis protocol and define a quality attribute that provides a clear description of the diversity efficiency characteristics of offline recorded communications.

RESEARCH OBJECTIVES

1. My objective is **to develop a scenario plan** and a **graphical test method** suitable for **model-level investigation** of the applicability, capabilities and limitations of short-wave band **direction-finding sensor arrays**.
2. My goal is **to develop a methodological recommendation** that is more suitable than conventional methods **for comparative analysis of diversity signal combination modes**.
3. My objective is **to develop a test pattern protocol** and **testing it** on real recorded results for a receiver diversity measurement suitable **for investigating diversity reception characteristics on arbitrary diversity types using message-level data**.
4. My objective is **to define the concept of Relative Diversity Efficiency** and to demonstrate the relative content surplus, difference and descriptive ability of this new characteristics to diversity gain.

RESEARCH HYPOTHESES

Based on the scientific problem and the research objectives, I formulate the following hypotheses:

1. Hungary's short-wave **direction finding and location capability** for strategic data acquisition **has not been investigated** and **there are no data available to provide a basis for a decision of a system-wide improvement**. I would assume that the development and application of a graphical scenario-based test procedure **could answer** the question **whether a shortwave band goniobased sensor arrangement can be developed** which is capable of detecting, measuring the direction and determining the position of large number signal sources on the territory of Hungary, either independently or in the framework of international cooperation, as part of a strategic data acquisition system.
2. The **options for improving the quality** of fault performance of short-wave multi-sensor receiver systems **are not known**. My hypotheses is that **by developing a multi-criteria test concept, a niche methodological requirements framework can be introduced** that is equally **suitable for comparative simulation analysis of diversity signal combination methods**, and that a content-definable shortwave band adapted receiver diversity test and evaluation method based on measurement data processing with synthesis-based processing can be created.
3. In my view, **there is currently no generally applicable methodology** that provides an accurate assessment of the true announcement-level profit characteristics of buyer diversity structures. I hypothesize that an **offline analysis method that examines the individual and joint diversity properties of sensors** and **can provide more detailed and multi-spectral evaluation options compared to conventional procedures.**
4. I hypothesize that the **Diversity Gain System Characteristic** for the conventional approach to measuring the effectiveness of diversity signal combination methods in the communication-based test of receiver diversity methods **does not characterizes l-world gain situation**. With a new type of processing method for sensor data, the concept of **Diversity Efficiency can be introduced**, which shows the real-world conditions and efficiency of diversity-based signal combining on a quantitative basis more clearly than gain.

RESEARCH METHODOLOGIES

In preparing my thesis, I used the following research methods:

- literary research;
- processing of relevant literature in Hungarian and foreign languages (English, German, Russian, Serbian, Bosnian, Croatian), with particular emphasis on the study of works of scientific value in the field of research;
- analysis of written and electronic publications, standards, recommendations, conference and seminar materials;
- participation in online forums and conferences;
- research and processing of other sources;
- participation in professional events and conferences as a speaker and participant;
- logical analysis, analytical processing and evaluation of measurement results, with drawing conclusions and recommendations;
- qualitative and quantitative processing of primary research data;
- numerical analysis;
- inductive and deductive reasoning approaches;
- generalisation;
- comparative analysis;
- exploring relationships;
- secondary analysis of research;
- modelling;
- expert consultation;
- empirical use of decades of professional experience;
- publishing and teaching research results.

THE CONCISE DESCRIPTION OF THE EXAMINATION CONDUCTED

In the structure of my thesis, I tried to take a systematic approach to the topic, building on the logical connection of scientific problems, research objectives, hypotheses and methods.

In my discussion, I followed the principle of building on the hypotheses and research objectives.

On this basis, **in the first chapter,** I would review the general environmental conditions for strategic data acquisition for shortwave national security purposes, which will provide the framework for my research. I describe the role of shortwave telecommunications in the communications needs of our present time, the legal framework for clandestine information collection, and the band-specific characteristics and novel technological challenges of data acquisition.

In the second chapter, I give an estimation of the achievable capabilities and limitations of a shortwave direction finding and location system in Hungary by defining typical feasibility scenarios and a prioritized set of criteria.

In the third chapter, based on a taxonomic summary of diversity reception methods, I present the characteristics of conventional and evolutionary algorithm-based signal combination methods and I describe the method of their simulation study in detail.

In the fourth chapter, in more details, I describe the methodological design and the results of the application of my measurement data evaluation procedure using real data from diversity measurements and I also propose a new conceptual definition of diversity efficiency.

A systematically summarized table of the scientific sources processed and partially cited in this thesis, a table of HF bandwidth usage, a summary list of shortwave decoders and modulation modes, the script contents of the signal combination simulation runs performed, a summary table of the raw data of the diversity measurements and additional technical data sheets are provided **in the Appendices**.

SUMMARIZED CONCLUSIONS

1. There are limited scientific evidence in the peer-reviewed scientific literature that is itself, suitable for a communication-level assessment and evaluation of the effectiveness of customer diversity management.
2. The utilisation of the Hungarian territory as a shortwave directional goniobase element results in a double perception from a geographical point of view. In the context of a standalone and Visegrád 4 three-point sensor system, the area of neighbouring countries provides the target area that can be localised with maximum accuracy, while a direction-finding sensor in Hungary in the context of NATO cooperation in an easterly direction has a substantial contribution potential in terms of the reliability of positioning results.
3. The developed novel simulation-based test method can provide more comprehensive information compared to conventional methods in the analysis and multi-spectral investigation of the radio channel characteristics of diversity signal combining techniques.
4. The developed receiver diversity testing sample protocol fills in a methodological gap that has not been published so far. The analysis procedure covers novel analysis possibilities for which previous conventional methods are not suitable in the context of the analysis of diversity receiver characteristics based on communication-level data.
5. The use of the concept of **Relative Diversity Increment** in addition to the **Diversity Gain** characteristic is justified in the bulletin-level analysis of diversity receiving processes.

NEW SCIENTIFIC ACHIEVEMENTS

I summarise my scientific research and studies as follows:

1. I have developed a multi-scenario design mode and a graphical test method suitable for model-level investigation of the applicability, capabilities and limitations of shortwave band goniobased sensor arrays.
2. I have developed a methodological protocol suitable for simulation-based comparative analysis of diversity signal combination methods.
3. I have developed and tested an evaluation-analysis method on real measurement data that incorporates both quantitative and qualitative elements that are generally applicable in diversity signal combining.
4. I have defined a new terminological element, the concept of Relative Diversity Increment, to a more precise description of the receiver diversity announcement level analyses.

FURTHER PERSPECTIVES OF DEVELOPMENT

A model-based comparison of evolutionary algorithm-based weighting factor methods with SC, EGC, MRC methods would provide new comparison results that would open a new dimension in the analysis of diversity efficiency. One of the outstanding advantages of heuristic methods is that they achieve an improvement in the quality of the output signal of the diversity receiver by a prediction method, an algorithm-based modification of the weight factors. Adaptive algorithms are able to calculate optimal values for the weighted consideration of the signals of each diversity branch by estimation, using variable parameters modified in the process.

Today, the use of AI is becoming more and more widespread in all areas of engineering. Artificial intelligence can make decisions autonomously, without operator intervention, to achieve a better quality result (in our case, increasing output SNR). Hence, a particular perspective can be opened for research on artificial intelligence-based signal combining techniques. In my source search, I did not come across any scientific publications of this kind concerening the study of diversity signal selection

decision theory, and I see potential research opportunities for further research in this area. In my opinion, this area is a pioneering research direction.

The incorporation of complex channel models into the simulation process could also represent a novel approach. In my research, I investigated basic radio channel models with empirical description methods. For the theoretical investigation of shortwave signal propagation, research results are already available (Watterson model, ITU-R-HF models) that specifically allow the description of radio channel characteristics in the 3-30 MHz frequency range at the model level. Matlab-based simulation studies of both models could provide, in addition to the research results, valuable results for education.

Performing discrete, SDR-based online measurements with two sensors would also contribute to the methodology for evaluating the measured, real-world results.

RECOMMENDATIONS FOR THE PRACTICAL USE OF RESEARCH RESULTS

I recommend the use achievements of the thesis for educational purposes at BSc, MSc and PhD levels in the fields of telecommunications, info communications, communications and national security as independent teaching material, as source work or as recommended professional literature.

For further exploitation, the material could be used not only in education but also in the professional work of national security services in this field.

The simulation analysis method created is suitable for use as a template for other evaluation processes on measured data.

MY PUBLICATIONS

Scientific publications in the subject:

1. Kovács, Róbert: The History of First High Frequency Diversity Reception Techniques, Hadmérnök, VIII. Vol. 1. pp.225-232. (2013), ISSN 1788-1919
   Source: http://hadmernok.hu/2013_1_kovacsr_2.php (Accessed: 13.07.2022.)

2. Kovács, Róbert: Diversity Reception in Radiocommunication Links, Hadmérnök, VIII. Vol.1. pp. 215-224. (2013) ISSN 1788-1919
   Source: http://hadmernok.hu/2013_1_kovacsr_1.php (Accessed: 13.07.2022.)

3. Kovács, Róbert: Nemzetbiztonsági célú rövidhullámú stratégiai COMINT rendszerek elektronikai védelmi megfontolásai, Nemzetbiztonsági Szemle. III. Vol. 2. (2015) pp. 52-70. HU ISSN 2064-3756

4. Kovács, Róbert: Diversity as a Novel, Widespread Receiving Technology, Társadalom és Honvédelem, XVII. Vol. 3-4. pp.149-171. (2013), ISSN 1417-7293

5. Kovács Róbert: Aspects of Propagation Prediction Methods, Nemzetbiztonsági Szemle. (2016) HU ISSN 2064-3756 / Declaration of admission /

6. Kovács Róbert: Az akusztikus közegből történő információgyűjtés fejlődése, In: Boda-Dobák: A nemzetbiztonság technikai kihívásai a 21. században, NKE University note, Chapter 5.3, pp.58-67. NKE Szolgáltató Nonprofit Kft, Budapest, 2015., 174 p. ISBN 978-615-5527-74-6

7. Kovács Róbert: Térinformatikai fogalmak és felhasználási lehetőségek a többforrású adatfúziós rádiófelderítő rendszerekben, Nemzetbiztonsági Szemle 2016. Vol. 2. pp. 83-100. ISSN 2064-3756

Other scientific publications:

8. Kovács Róbert, Kún Gergely, Nádai László, Varga Péter János, Gyányi Sándor, Wührl Tibor, Mészáros Kristóf: 5G Research in Kandó
In: Szakál, Anikó (editor) 21th IEEE International Symposium on Computational Intelligence and Informatics (CINTI 2021)
Piscataway (NJ), USA: IEEE (2021) 273 p. pp. 217-222., 6 p.

9. Kún Gergely, Kovács Róbert, Wührl Tibor, Mészáros Kristóf, Nádai László, Gyányi Sándor, Varga Péter János: Introduction of 5G in Education
In: Nádai, László 2021 IEEE 4rd International Conference and Workshop in Óbuda on Electrical and Power Engineering (CANDO-EPE)
Piscataway (NJ), USA: IEEE (2021) 197 p. pp. 147-152., 6 p.

10. Varga Péter János, Nádai László, Tóth András Bálint, Kail Eszter, Wührl Tibor, Gyányi Sándor, Kún Gergely, Kovács Róbert, Bánáti Anna, Kozlovszky Miklós: 5G RAN Research in Óbuda University
In: Szakál, Anikó (editor) IEEE 20th Jubilee World Symposium on Applied Machine Intelligence and Informatics SAMI (2022): Proceedings, Poprad, Szlovákia: IEEE (2022) 507 p. pp. 359-365., 7 p.

11. Kún Gergely, Varga Péter János, Wührl Tibor, Wührl Dóra, Gyányi Sándor, Nádai László, Kovács Róbert: „Opened" or „Closed" RAN in 5G
In: Szakál, Anikó (editor) IEEE 20th Jubilee World Symposium on Applied Machine Intelligence and Informatics SAMI (2022): Proceedings
Poprad, Szlovákia: IEEE (2022) 507 p. pp. 347-351., 5 p.

PROFESSIONAL-SCIENTIFIC CURRICULUM VITAE

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2016- Óbuda University, Kandó Kálmán Faculty of Electrical Engineering, Department of Communications and Infocommunications, Deputy Head of Department, Assistant Professor

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Language skills:

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- NATO STANAG 6001 SLP certified international professional language exam in English
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