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ISSUE №64

4TH INTERNATIONAL SCIENTIFIC AND PRACTICAL CONFERENCE

INNOVATIVE RESEARCH IN SCIENCE AND ECONOMY

APRIL 1-3, 2026
BRUSSELS, BELGIUM

INTERNATIONAL SCIENTIFIC UNITY

4th International Scientific and Practical Conference

«Innovative Research in Science and Economy»

Collection of Scientific Papers

April 1-3, 2026
Brussels, Belgium

UDC 001(08)

Innovative Research in Science and Economy: Collection of Scientific Papers with Proceedings of the 4th International Scientific and Practical Conference. International Scientific Unity. Brussels, Belgium. April 1-3, 2026.

ISBN 979-8-89704-976-9 (series)
DOI 10.70286/ISU-01.04.2026

The conference is included in the Academic Research Index ReserchBib International catalog of scientific conferences.

ISBN 979-8-89704-976-9

Official site: https://isu-conference.com/

METHOD FOR INTEGRATED ASSESSMENT OF STRUCTURAL STABILITY OF COMPLEX SIGNAL ENSEMBLES USING ENTROPY-BASED ANALYSIS

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Modern telecommunication networks, in particular cognitive radio networks, operate under conditions of high spectral environment dynamics and dense utilization of frequency resources. Under such conditions, the problem of forming ensembles of complex signals with controlled correlation and structural characteristics becomes highly relevant in order to ensure interference resistance and efficient operation of multiple access systems.

In previous studies, methods for optimizing signal ensembles in the time domain have been developed, in particular the deterministic LPT-τ permutation method (LPT-TP) and the predictive method based on Markov models (Markov-forecast) [1–3]. Their comparative characteristics are presented in Table 1, which allows evaluating the differences in optimization approaches and the use of entropy-based characteristics.

Table 1 – Comparison of optimization methods

Criterion	LPT-τ permutation method (LPT-TP)	Markov-based permutation method
Main mechanism	Deterministic time restructuring based on low-discrepancy τ-sequences	Predictive selection of permutations based on Markov transition probabilities
Optimization objective	Minimization of correlation (PSL/ISL) and maximization of ensemble size ($S_{complex}$)	Minimization of the predicted correlation level $E[\rho_{t+1}]$ and control of transition stability
Control parameter	Shift parameter τ^*	Uncertainty coefficient β
Relation to entropy	Entropy (PE, SampEn, FuzzyEn) is used for post-analysis of structural complexity	Entropy $U(\pi_i)$ is used as a control component to penalize instability within the criterion $K(\pi_i)$

Despite the effectiveness of the considered methods in reducing signal correlation, they do not provide a comprehensive assessment of the structural ordering of the signal ensemble. This necessitates the use of multiscale entropy analysis as a universal tool for the quantitative evaluation of signal complexity.

The formation of a signal ensemble in the LPT-TP method is based on deterministic permutations of time segments using the shift parameter τ, whose optimization is performed according to an integral criterion (Fig. 1).

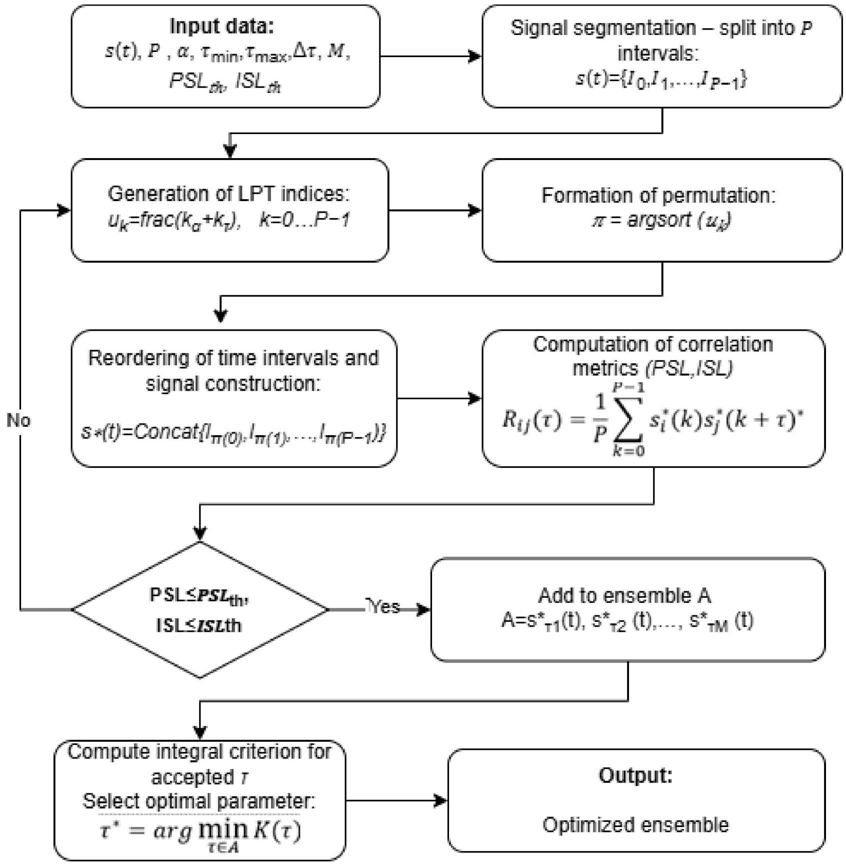

Figure 1 – Structural diagram of the LPT-τ permutation method

To evaluate the structural ordering of signal ensembles, multiscale entropy analysis was applied using the following metrics: Sample Entropy, Permutation Entropy, Fuzzy Entropy, and Dispersion Entropy. The results of this analysis are presented in Table 2 and Fig. 2, which illustrate the dependence of entropy measures on the scale and noise level.

Table 2 – Entropy measures of signal ensembles formed using the LPT-τ permutation method

Scale	SNR	Sample Entropy	Permutation Entropy	Fuzzy Entropy	Dispersion Entropy
1	–10 dB	0,38	0,95	0,90	0,70
	–5 dB	0,37	0,90	0,86	0,68
	0 dB	0,36	0,85	0,82	0,66
	5 dB	0,35	0,78	0,78	0,64
	10 dB	0,34	0,70	0,74	0,62
	Optimized	0,33	0,50	0,63	0,59
3	–10 dB	0,50	0,79	0,75	0,67
	0 dB	0,47	0,69	0,69	0,64
	Optimized	0,44	0,54	0,67	0,61
5	–10 dB	0,57	0,67	0,68	0,65
	0 dB	0,53	0,59	0,64	0,63
	Optimized	0,50	0,57	0,69	0,62
10	–10 dB	0,75	0,77	0,76	0,72
	0 dB	0,71	0,75	0,74	0,70
	Optimized	0,68	0,72	0,77	0,67

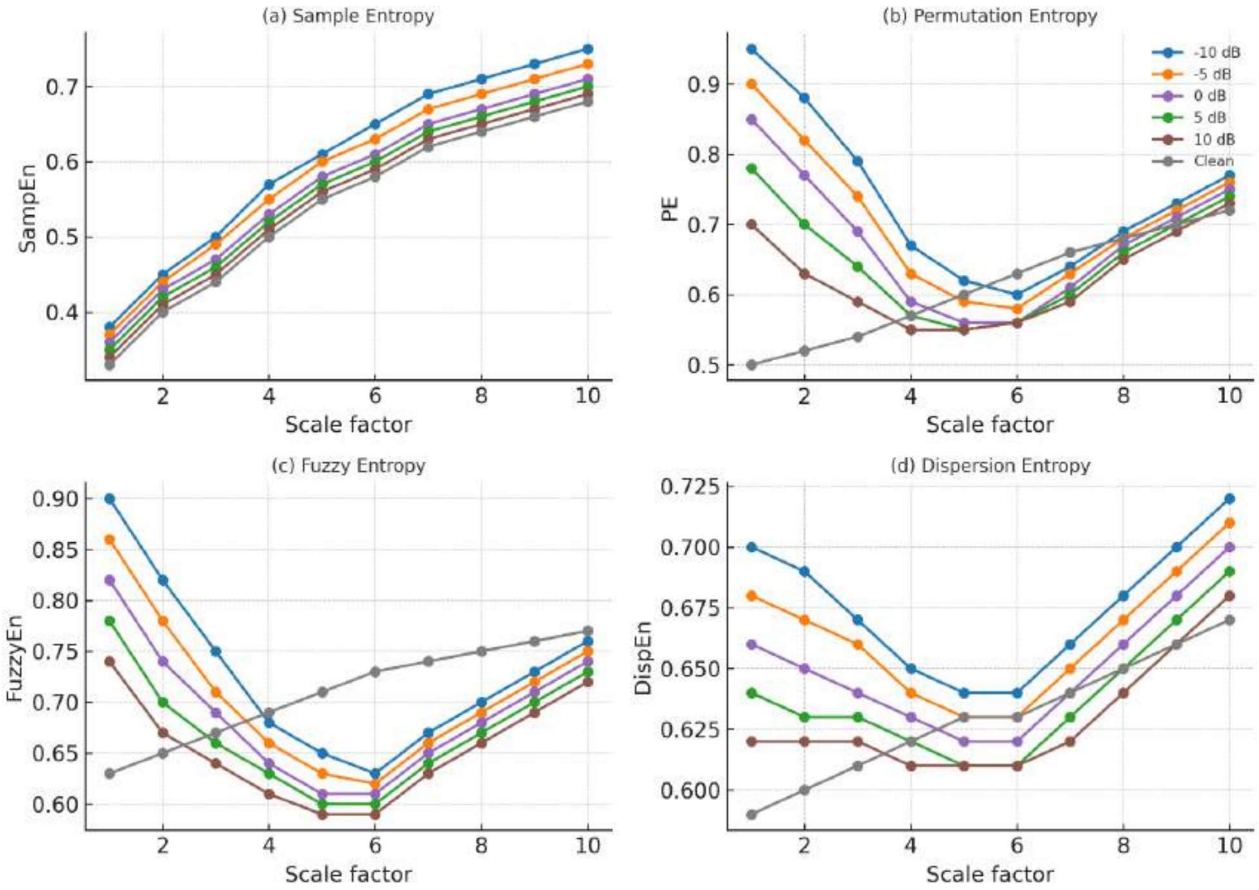

Figure 2 – Multiscale entropy analysis of signal ensembles formed using the LPT-τ permutation

The analysis of the results indicates that optimized signal ensembles demonstrate a consistent decrease in entropy measures compared to non-optimized ones. In particular, for scale 1, the value of Permutation Entropy decreases from 0,95 to 0,50, while Fuzzy Entropy decreases from 0,90 to 0,63, indicating an increase in the structural ordering of the signals.

To overcome the limitations of the deterministic approach, the Markov-forecast method was developed, which is based on probabilistic modeling of transitions between ensemble states. The proposed approach enables adaptive reduction of correlation and ensures a more stable evolution of entropy characteristics (Fig. 3).

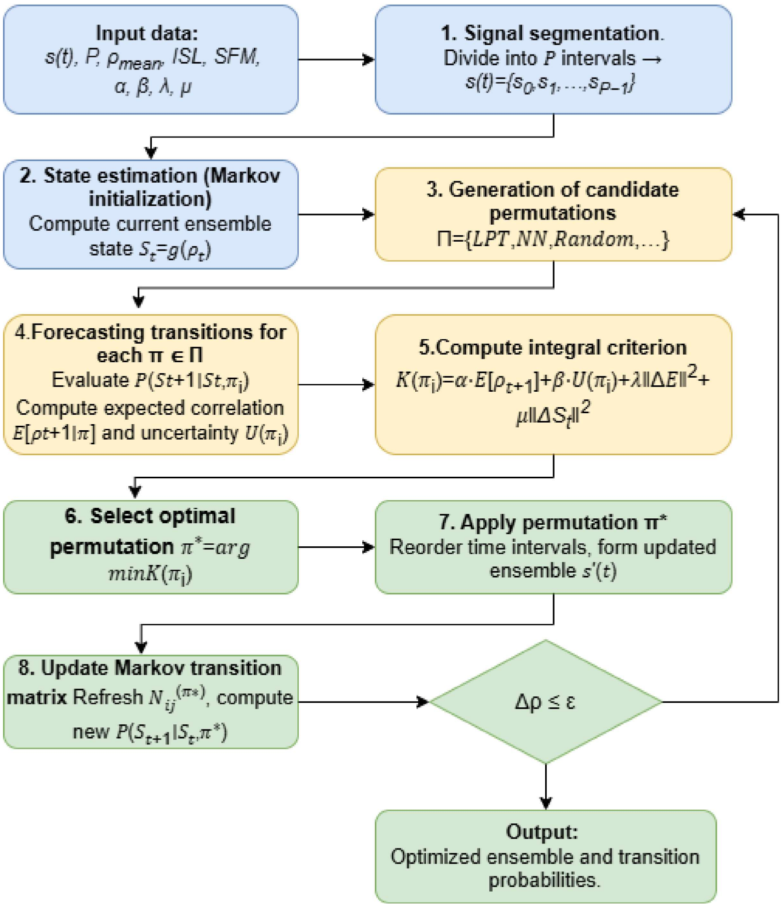

Figure 4 – Algorithm of the time-permutation method based on Markov models

The simulation results showed that the application of the Markov-based approach provides a reduction in entropy measures by 8–15%, as well as a decrease in the average correlation and the integral optimality criterion by up to 30–40%, which confirms the improvement of the structural stability of the signal ensemble (Table 3).

Table 3 – Entropy measures of signal ensembles formed using Markov-based models

Scale	SNR	Sample Entropy	Permutation Entropy	Fuzzy Entropy	Dispersion Entropy
1	−10 dB	0,39	0,97	0,91	0,71
	−5 dB	0,38	0,92	0,88	0,69
	0 dB	0,37	0,87	0,84	0,67
	5 dB	0,36	0,80	0,80	0,65
	10 dB	0,35	0,73	0,76	0,63
	Optimized	0.35	0,56	0,66	0,62
3	−10 dB	0,51	0,82	0,78	0,69
	0 dB	0,47	0,70	0,70	0,65
	Optimized	0,44	0,58	0,65	0,62
5	−10 dB	0,58	0,70	0,70	0,66
	0 dB	0,54	0,62	0,66	0,64
	Optimized	0,51	0,57	0,64	0,62
10	−10 dB	0,77	0,79	0,78	0,73
	0 dB	0,73	0,77	0,76	0,71
	Optimized	0,70	0,74	0,74	0,69

Thus, the proposed approach enables the integration of entropy-based metrics with optimization parameters of signal ensembles, ensuring their consistency, predictability, and robustness to interference in cognitive telecommunication networks.

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ВПЛИВ ОБРОБКИ ВИБУХОМ НА МАЛОЦИКЛОВУ ДОВГОВІЧНІСТЬ СТАЛІ

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У тезах розглянуто вплив зміцнювальної обробки вибухом на механічні властивості та малоциклову довговічність сталі 20 [4, 5]. Показано, що основним параметром вибухового зміцнення є тиск на фронті ударної хвилі, підвищення якого зумовлює зростання мікротвердості, межі текучості, тимчасового опору розриву та зусилля деформування при статичному згині [4, 7]. Встановлено, що зі зростанням тиску на фронті ударної хвилі в структурі сталі активізуються процеси двійникування та формується текстурований стан металу [4]. Водночас ефективність вибухового зміцнення щодо підвищення малоциклової довговічності визначається не лише рівнем тиску, а й амплітудою пружно-пластичної деформації та умовами робочого середовища [6]. За невисоких амплітуд циклічної деформації обробка вибухом сприяє зростанню довговічності, тоді як за високих амплітуд спостерігається зворотна тенденція,

Collection of Scientific Papers
with Proceedings of the 4th International Scientific and Practical Conference
«Innovative Research in Science and Economy»
April 1-3, 2026
Brussels, Belgium

Contact details of the organizing committee:
Sole Proprietor Viktoriia Tsiundyk
E-mail: info@isu-conference.com
URL: https://isu-conference.com/

Certificate of the subject of the publishing business: ДК №7980 of 03.11.2023.

INTERNATIONAL SCIENTIFIC UNITY