allows for flexibility and adaptability in signal processing while maintaining a low level of correlation between components. Accounting for nonlinear components using Volterra equations enables a multistep approach to modeling signal changes, ensuring high accuracy and uniqueness (Fig.1).

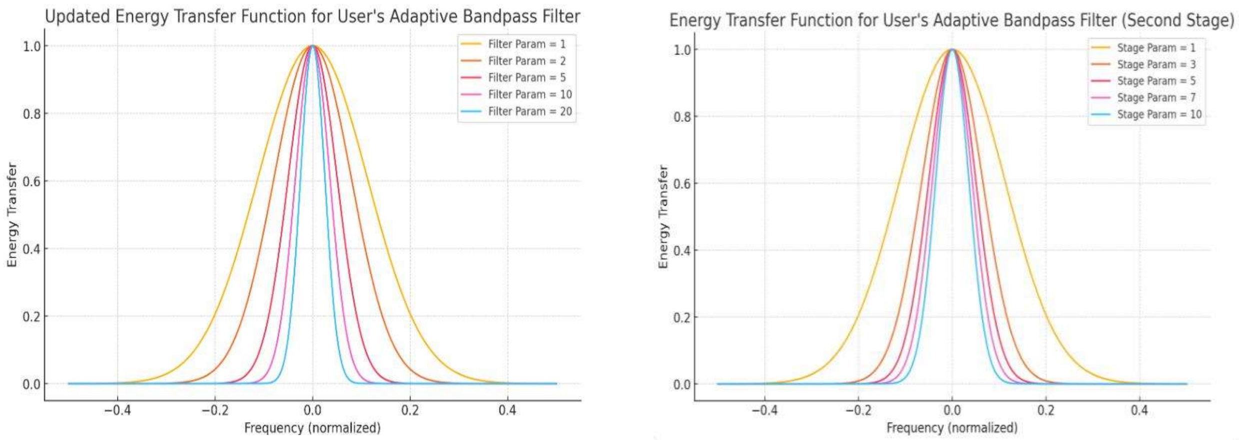

Fig. 1 Energy transfer functions before and after filtering for hybrid time segmentation

The proposed method not only transitions to the time domain but also integrates time and frequency analysis, taking into account variable signal parameters. This creates a more flexible model for signal ensemble formation, suited to real-world conditions in complex interference environments.

*L'Hôpital’s rule is named after the French mathematician Guillaume de l'Hôpital. It is a mathematical principle used primarily in calculus to analyze the limits of indeterminate forms, especially when functions approach 0/0 or ∞/∞. The rule applies in mathematical contexts where derivatives help in determining the limit of a function at critical points

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УДК 621.396.967

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SPECTRAL MONITORING METHOD BASED ON MULTISTAGE FILTERING AND AIC & BAYESIAN INFORMATION CRITERIA

The relevance of implementing multistage recurrent spectral monitoring methods with adaptation to dynamic radio environments is driven by several key factors. Firstly, the growing use of wireless technologies has led to an increase in the number of devices, which in turn creates significant pressure on the frequency spectrum. Secondly, the limited availability of frequency resources makes the efficient use of the spectrum a critically important task in modern telecommunication systems. Thirdly, the dynamic nature of the spectral environment, characterized by rapid changes, necessitates the use of adaptive methods capable of ensuring stable and reliable operation of cognitive radio systems. Given these challenges, the implementation of a multistage recurrent spectral monitoring method with adaptation to dynamic cognitive radio environments, particularly under conditions of fading and distortions, becomes essential. This method involves multistep filtering processes (Kalman filters, Wiener filters, and median filters) and the application of Akaike and

Bayesian criteria to optimize spectral efficiency and maintain robust system performance.

Such an approach ensures that the cognitive radio network can dynamically adapt to changes in the spectral environment, improving both spectral utilization and the quality of communication, even in challenging conditions with high levels of interference and variability. This combination of multistage filtering and rigorous statistical analysis represents a significant advancement in spectral monitoring, making it a highly effective solution for modern wireless communication systems. Main stages of the method.

1. Initial spectrum measurement. This stage involves the initial analysis of the spectrum to gather data on the frequency range, which is necessary for further filtering and modeling.

2. Preliminary signal filtering. Kalman filters are used at this stage for preliminary signal filtering to reduce noise and account for fading. The Kalman filter is effective because it works well with dynamic systems and incorporates previous state information, reducing noise and improving signal quality before further analysis.

3. Using the Akaike Information Criterion (AIC). AIC is applied for the initial evaluation of spectral models, allowing the selection of the optimal model for the spectral data. Other information criteria, such as BIC or Minimum Description Length (MDL), could also be used, but AIC is preferred in the early stages due to its balance between accuracy and computational complexity.

4. Window width selection. The window width is set based on the signal type:

GSM: 200 kHz
Wi-Fi: 20 MHz (802.11b/g/n)
Bluetooth: 1 MHz
FM Radio: 200 kHz
TV: 6-8 MHz
LoRaWAN: 125 kHz or 500 kHz

5. Adaptive signal filtering: Different filters are used for various signal types:

– Wiener filter: Ideal for reducing noise in signals with stable spectral structures (e.g., Wi-Fi, FM Radio).

– Median filter: Suitable for eliminating impulse noise and distortions in highly dynamic signals (e.g., Bluetooth, LoRaWAN).

6. Bayesian Information Criterion (BIC). BIC is used at later stages to refine the models and avoid overfitting. BIC provides a stricter evaluation of the models by considering the number of model parameters.

7. Kullback-Leibler Divergence calculation. This metric is used to evaluate the quality of the models by measuring the divergence between two probability distributions, helping to assess how well the model fits the actual data.

8. Akaike weight calculation. Akaike weights are calculated to determine the relative quality of models and compare how well they fit the observations. If Akaike weights exceed certain thresholds, the sub-band is considered available for secondary users; otherwise, it is deemed occupied.

9. Multistage recurrent time segmentation. Time series are segmented to improve the accuracy of detecting changes in the spectral environment. This reduces computational resources by focusing on critical segments of the signal.

10. Recursive updating of spectral estimates. Spectral estimates are continuously updated based on new data, ensuring dynamic adaptation of the method to changes in the spectral environment.

The proposed method combines classical filtering techniques with modern information criteria to enhance spectral monitoring accuracy. This method is particularly suited for real-time spectrum monitoring in environments with high levels of noise, interference, and spectral variability.

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ПІДВИЩЕННЯ ЕФЕКТИВНОСТІ ВИКОРИСТАННЯ ЗАЛІЗНИЧНОЇ ІНФРАСТРУКТУРИ ШЛЯХОМ ПРОГНОЗУВАННЯ ОБСЯГІВ ПЕРЕВЕЗЕННЯ ВАНТАЖІВ

Зростання конкуренції між різними видами транспорту та зношеність основних засобів залізничного транспорту в перспективі можуть призвести до втрати частки ринку перевезень