ANNOTATION

of the dissertation thesis for the degree of Doctor of Philosophy (PhD) in the educational program «8D06201 – Radioengineering, electronics and telecommunications»

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INFORMATION-ENTROPY METHOD OF ROUTING WIRELESS NETWORKS

Relevance of the work. Currently, Wireless Mesh Networks (WMNs) are among the most significant and rapidly developing communication technologies. Their popularity is driven by several key advantages, such as ease of deployment, self-healing capabilities, self-organization, and high cost-efficiency. Due to these characteristics, WMNs provide stable and flexible connectivity in dynamic and high-load network environments, particularly in areas with complex urban infrastructure, industrial facilities, and in scenarios requiring a high degree of network autonomy.

Despite the considerable potential of WMNs, a number of existing challenges hinder their optimal performance. The dynamic topology and constantly changing channel conditions complicate the uniform distribution of nodes, which reduces routing speed and may lead to uneven load distribution. Traditional routing algorithms struggle to adapt to such changes, which negatively affects throughput and communication reliability. The effects of noise and multipath propagation lead to signal reception errors and an increase in the BER, which in turn degrades the quality of demodulation.

To ensure reliable and adaptive performance of WMNs in environments with dynamic topology, variable channel conditions, and high levels of noise and interference, it is necessary to develop innovative methods capable of addressing current network issues. Specifically, there is a need for algorithms that ensure accurate signal reception, balanced node distribution to enhance routing speed, and the selection of routes with high channel throughput and minimized BER. This need arises from the fact that traditional routing methods do not always cope well with the constant changes in transmission conditions, which negatively impacts the quality of communication. Thus, the development of methods for automatic modulation classification, network clustering, and routing based on information entropy is essential for optimizing routing and improving the overall efficiency of WMNs.

The aim of this work is to optimize the network structure and routing in WMNs by developing innovative algorithms, including a modulation type classification algorithm for reliable signal reception, CIEA for improving routing speed, and IERA for enhancing reception reliability and network throughput.

Research objectives:

1. To develop a modulation type classification algorithm aimed at reducing reception errors and improving the performance of routing algorithms.
2. To develop the CIEA algorithm based on the box-covering theory for optimal clustering of the WMN, calculating the fractal dimension of the network, and ensuring high routing speed.
3. To create a routing algorithm based on the theory of information entropy (IERA), which constructs routes based on the maximum value of conditional path information and channel capacity in WMNs, in order to increase data transmission speed and reduce bit error rate.

Objects of research: wireless mesh network (WMN).

The research method:

This work employs methods from graph theory, information theory, numerical modeling − including NS3 − and software implementation in Python, as well as experimental signal transmission using MIMO antennas.

The box-covering method from graph theory is used to divide complex networks into clusters, enabling their analysis and optimizing routing processes. Methods of information theory focus on analyzing the information transmitted through the communication channel, allowing the evaluation of network capacity and bit error rate. Mutual information is employed as a key metric for reliable signal classification, ensuring the algorithm's robustness to noise.

The numerical modeling method (NS3) is applied to test existing algorithms under controlled conditions. It allows for analyzing the influence of network and signal parameters, predicting system behavior, and identifying optimal settings.

In addition, a real-world experiment was conducted involving signal transmission via MIMO antennas, a labor-intensive process requiring precise equipment calibration and consideration of the physical characteristics of the communication channel. The obtained real signals were processed using the proposed modulation classification algorithm, confirming its practical effectiveness.

The proposed methods were implemented in Python, enabling their validation through numerical simulation. For this purpose, Python libraries such as NetworkX for network modeling, NumPy and SciPy for computations, and visualization tools like Matplotlib and Seaborn were used.

The main provisions submitted for defense

1. The modulation classification algorithm based on mutual information theory ensures accurate identification of the modulation type of complex telecommunication signals at low signal-to-noise ratio (SNR) levels, specifically above 5 dB.

2. The Center-Inclusive Eccentricity Algorithm (CIEA), based on the box covering theory, enables uniform clustering of wireless mesh networks (WMNs) by router count, increasing routing speed by 20 microseconds for 3280 nodes compared to the classical Dijkstra algorithm.

3. The routing algorithm (IERA), which defines the maximum of conditional information as the difference between joint and conditional entropy of an ensemble (a set of noisy received signal values), improves the WMN throughput by 5 Mbps in numerical simulations with 100 nodes compared to the classical Dijkstra algorithm.

The scientific novelty of the work

This work introduces innovative algorithms for network optimization and routing in WMNs, considering the fractal properties of the network, transmission medium characteristics, and information-entropy-based criteria.

1. The developed modulation classification algorithm uses mutual information for the first time to extract statistical features of a modulated signal, enabling the capture of dependencies between variables and improving classification accuracy by 50% compared to the HOC-based algorithm.
2. The proposed CIEA algorithm, based on box covering theory, introduces the concept of eccentricity into clustering, achieving more optimal network coverage than existing clustering algorithms such as GC, OBCA, CBB, and MEMB.
3. The IERA routing algorithm constructs routes based on the maximum value of conditional information along a path in the WMN, optimizing data transmission speed and reducing bit error probability compared to existing routing algorithms including Dijkstra, ACO, OLSR, and AODV.

Theoretical and practical significance of the work

The developed and implemented algorithms − including the modulation type classification algorithm, CIEA, and IERA − have high theoretical and practical significance for WMNs. The theoretical contribution lies in presenting innovative approaches to network and routing optimization, accounting for critical aspects such as uniform and optimal network clustering, channel error probabilities, and gateway placement.

The practical value is supported by the successful implementation of these algorithms in WMN scenarios, addressing real-world challenges faced by network operators and end-users.

The CIEA algorithm enables uniform network clustering, enhancing routing speed. Meanwhile, the IERA algorithm, based on information entropy theory, determines routes with maximum conditional information, improving data transmission reliability and reducing bit error rate. Their practical applicability and effectiveness are demonstrated through their successful inclusion in a utility model patent, which describes a cluster router and a router based on information entropy.

Personal contribution of the author

All the main results submitted for defense were obtained by the applicant. The author's personal contribution includes conducting a literature review, writing and editing scientific articles, which contributed to the structuring and justification of the research; developing and modeling networks in Python and NS3 environments, enabling detailed analysis of wireless network performance and assessment of the effectiveness of the proposed solutions, including network clustering tasks; performing calculations of fractal dimensions necessary for studying the topological characteristics of the network and analyzing their impact on routing processes; implementing existing routing algorithms in Python and NS3 for comparative analysis with the proposed methods; participating in the development, software implementation, and testing of the proposed algorithms, including parameter optimization and code debugging; as well as conducting an experiment to collect real MIMO signals for automatic modulation classification, which confirmed the practical feasibility of the method.

The theoretical part was developed under the guidance of the academic advisor, while the calculations, software implementation, and experimental work were carried out by the author. Problem formulation and discussion of results were conducted jointly with scientific consultants.

Reliability of the results

The reliability of the scientific findings of this work is supported by modeling, numerical analysis, experimental evaluation, literature studies, as well as well-founded theoretical models and principles applied in the field of WMNs and routing. These models include mutual information, conditional information, and fractal dimensions, which provide a deep understanding of network structure and routing efficiency, and contribute to the development of more advanced algorithms for optimizing WMN performance.

Approbation of the work

8 publications have been published based on the materials of the dissertation work.

Articles with a high impact factor based on the Thomson Reuters database or in publications included in the international scientific database Scopus:

1. Ussipov N., Akhtanov S., Zhanabaev Z., Turlykozhayeva D., Karibayev B., Namazbayev T., & Tang X. (2024). Automatic modulation classification for MIMO system based on the mutual information feature extraction. *IEEE Access*.

2. Akhtanov S. N., Turlykozhayeva D. A., Ussipov N. M., Ibraimov M. K., Zhanabaev Z. Zh., 2022. Centre including eccentricity algorithm for complex networks. Electronics Letters, 58(7), 283-285.

3. Zhanabaev Z., Akhtanov S., Turlykozhayeva D., Ussipov N., & Ibraimov M., (2022). Cluster router based on eccentricity. Eurasian Physical Technical Journal, 19(3 (41)), 84-90.

4. Turlykozhayeva D. A., Akhtanov S. N., Ussipov, N. M., Akhmetali A., Bolysbay A., Shabdan, Y., 2023. Routing Algorithm for Software Defined Network Based on Boxcovering Algorithm. In 2023 10th International Conference on Wireless Networks and Mobile Communications (WINCOM) (pp. 1-5). IEEE.

5. Turlykozhayeva D. A., Akhtanov S. N., Baigaliyeva, A., Temesheva, S., Zhexebay D. M., Zaidyn M. & Skabylov A. (2024). EVALUATING ROUTING ALGORITHMS ACROSS DIFFERENT WIRELESS MESH NETWORK TOPOLOGIES USING NS-3 SIMULATOR. *Eurasian Physical Technical Journal*, *21*(2 (48)), 70-82.

6. Turlykozhayeva, D., Waldemar, W., Akhmetali, A., Ussipov, N., Temesheva, S., & Akhtanov, S. (2024). Single Gateway Placement in Wireless Mesh Networks. *Physical Sciences and Technology*, *11*(1-2).

7. Turlykozhayeva, D., Ussipov, N., Baigaliyeva, A., Temesheva, S., Bolysbay, A., Abrakhmatova, G., & Akhtanov, S. ROUTING METRIC AND PROTOCOL FOR WIRELESS MESH NETWORK BASED ON INFORMATION ENTROPY THEORY. Eurasian Physical Technical Journal. – 2023. – Т. 20. – №. 4 (46). – С. 90-98.

8. Turlykozhayeva, D. A., Akhtanov, S. N., Zhanabaev, Z. Z., Ussipov, N. M., & Akhmetali, A. (2025). A routing algorithm for wireless mesh network based on information entropy theory. *IET Communications*, *19*(1), e70011.

The relationship of the thesis topic with the plans of scientific work

The dissertation was carried out in accordance with the plans of the fundamental scientific research project funded by the Committee of Science of the Ministry of Science and Higher Education of the Republic of Kazakhstan under the grant “AP19674715 – Routing in Wireless Mesh Networks (WMN) Based on Box-Covering Algorithms.” As part of this project, the author has been working as a research associate to date, participating in the development and implementation of network optimization and routing algorithms for WMNs.

The structure and scope of the dissertation

The dissertation consists of an introduction, four main chapters, a conclusion, a list of references, and three appendices. The work is presented over 119 pages, illustrated with 60 figures, includes 46 formulas, 7 tables, and cites 125 bibliographic sources.