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Krakow, 12.09.2026

Review of the doctoral dissertation
by Rajiansyah, M.Sc., Eng.
titled
Management of a Communication Network: A Cooperative Game Approach

This review of the doctoral dissertation, authored by Mr. Rajiansyah, M.Sc., Eng., was commissioned by the Chairman of the Disciplinary Council for Technical Information Technology and Telecommunications, Mr. Wojciech Bożejko, prof. dr. hab. (Letter No. W4N-KP-SW.4110.8.2026 dated 25.06.2026). The supervisor of this dissertation is Mr. David Mark Ramsey, dr. hab. prof. associate at Wrocław University of Science and Technology, and the auxiliary supervisor is Mr. Dariusz Gąsior, dr. eng. The doctoral dissertation is written in English.

1. The research problem and its significance

The dissertation submitted for review presents an original solution—based on game theory—to a significant scientific problem concerning the efficient management and operation of complex communication networks; this problem requires not only optimal routing and resource utilization but also a fair distribution of the benefits derived from cooperation among providers.

The landscape of modern digital infrastructure has undergone a fundamental paradigm shift, evolving from isolated, centrally managed systems into complex communication networks based on multi-provider collaboration. Nowadays, organizations rarely rely on a single provider. The current standard involves combining resources from multiple tech giants (e.g., AWS, Microsoft Azure, Google Cloud) with those of local network service providers and data centers. The systems of these various providers must constantly and closely collaborate through continuous data exchange and network communication to ensure the smooth operation of modern applications and services. In this evolving environment, the dissertation by Mr. Rajiansyah, M.Sc., Eng., addresses a critical gap in contemporary network management: the reconciliation of technical optimization with the economic realities and strategic bargaining inherent in multi-provider environments. From this perspective, the issue addressed in the dissertation is of significant importance—both in scientific and practical terms.

The dissertation studies how the economic surplus created by routing communication demands through infrastructure controlled by several service providers can be modelled, maximized and allocated. A communication network is modeled by weighted graph. Edges of a weighted graph are assigned to providers; coalitions of providers combine links to serve demands; coalition values are derived from feasible or profitable routes; and cooperative-game solution concepts allocate the resulting profit. A capacity-free model (proposed in Chapter 4) is followed by a capacity-constrained multicommodity-flow formulation and by proposed economic-centrality measures (in Chapter 5).

The most important issue identified and evaluated in this research is the transition from purely technical efficiency to a model of fair economic distribution. Traditional network management has historically prioritized technical metrics—minimizing latency via Dijkstra's algorithm or finding the shortest path and optimizing cost-flow. However, the author correctly posits that in a decentralized world where different providers control different segments of a route, technical efficiency alone is insufficient to ensure participation. Without a mechanism for the fair distribution of profits generated by cooperative routing, the stability of the entire infrastructure remains at risk. This problem is profoundly scientific, requiring the integration of graph theory with algorithmic game theory, while maintaining acute practical significance for modern multi-operator environments like cloud computing hubs and ISPs, for example.

In the dissertation, the practicality of the proposed solutions is addressed through a clear logical progression. The basic model, in Chapter 4, analyzes linear transmission costs without capacity constraints, providing a baseline for coalition behavior and profit generation. The extended model proposed in Chapter 5 serves as a bridge to real-world ISP practicality, as it introduces capacity constraints and congestion effects. It acknowledges that resources are finite, and a coalition may not serve all demand even if it controls a feasible path. This research contributes to the creation of network management tools and provides a basis for future research on advanced, dynamic systems.

A critical analysis of how the proposed framework operates in practice was undertaken using theoretical and illustrative examples across Chapters 3, 4, and 5 (specifically in Sections 3.4, 4.6, and 5.5–5.8). Although computational procedures in Python were implemented to automate calculations for the model without capacity constraints model, the evaluation relies on synthetic and stylized network topologies, with no runtime study, empirical field validation, or large-scale testing on operational networks supplied (which the author explicitly lists as limitations of their study in Section 6.2).

2. Author's contribution

The dissertation introduces novel profit-allocation mechanisms grounded in cooperative game theory—specifically leveraging the Shapley value, Myerson value, and S-value—to guarantee a fair distribution of network profits among collaborating providers. Thus, the primary research objective, clearly formulated in Section 1.2.1, has been achieved.
Harmonizing network flow optimization with strategic game theory, Mr. Rajiansyah makes several original and impactful contributions to the field. The author's primary original contribution lies in the development of a unified coalition-based framework that models multi-provider communication networks as cooperative games on weighted graphs. Within this framework, the author formulates novel characteristic functions under linear costs (v_1 representing strict topological control and v_2 capturing economic control via second-price auction logic). Furthermore, the dissertation extends this foundational model to realistic, capacity-constrained environments by integrating multicommodity flow optimization with an iterative flow augmentation procedure. To overcome the exponential computational complexity inherent in traditional game-theoretic solution concepts, the candidate introduces flow-aware economic centrality measures (incorporating uniform and cost-proportional profit splits along shortest paths) as efficient, scalable alternatives. Finally, the author pioneers the application of graph-restricted cooperative games using relational graphs, Myerson values, and probabilistic S-values to capture the topological and structural constraints that dictate realistic coalition formation among independent network operators.

The dissertation effectively addresses the eight declared objectives outlined in Section 1.2.2, encompassing the formalization of the cooperative game model, the definition of the characteristic functions (v_1 and v_2), the integration of capacity constraints, and the development of axiomatic profit-allocation rules. The author successfully delivers a comprehensive modelling framework and an analysis of provider importance via economic centrality.

The eight research hypotheses from Section 1.3 are generally positively confirmed. The author demonstrates that representing providers as players in a cooperative game effectively captures their interdependence and that game-theoretic measures outperform purely structural ones in reflecting economic value. The only reservation concerns the sixth hypothesis in the chapter under discussion. Let us denote this hypothesis as H6. This hypothesis states: "We hypothesize that cooperative game-theoretic allocation methods, such as the Shapley value, Myerson value, and S-value, ensure a fair and stable distribution of profits among providers." The general formulation of this hypothesis is too broad, as the Shapley or Myerson value guarantees axiomatic fairness but does not automatically guarantee core stability (the lack of incentive for sub-coalitions to defect) for all games (as illustrated by the author's example in Figure 2.13). Guaranteed core membership of the Shapley value (payoff vector stability) requires specific mathematical properties, such as game convexity, which are not always present in network games. In writing H6, the author likely conflated the meanings of terms such as "fairness" and "stability"—as can happen in informal language; further comments on this matter are provided in point 3 of this review.

The contributions declared by the author in Chapter 1.5 align with the actual achievements. The only reservation concerns the fourth contribution (Section 1.5)—closely related to hypothesis H6 – and is purely interpretive in nature (the identification of fairness with stability, as already mentioned above in relation to H6).

While the central research problem—reconciling technical routing optimization with economic profit sharing in multi-provider networks—is undeniably practical and increasingly critical for modern digital infrastructure, the proposed game-theoretic solutions remain predominantly theoretical and analytical. In real-world operational environments, exact cooperative solution concepts such as the Shapley and Myerson values face substantial deployment hurdles due to the exponential computational complexity required to evaluate all possible provider coalitions, alongside simplifying assumptions regarding static network topologies and linear transmission costs. Nevertheless, the candidate partially bridges this practicality gap by introducing flow-aware economic centrality measures, which provide a computationally lightweight and scalable alternative for revenue allocation based on grand-coalition traffic without requiring full combinatorial calculations. Overall, while the dissertation establishes an important theoretical foundation, the proposed mechanisms require further operational refinement—such as dynamic cost modeling, decentralized protocol implementation, and empirical field testing—before they can be directly integrated into commercial multi-operator network control planes.

It should be emphasized that the author has demonstrated high research maturity by transparently identifying the limitations of his own models in Chapter 6 (Sections 6.1 and 6.2)—including the exponential computational complexity, the lack of full algorithmic automation for capacity-constrained games, the assumption of a static topology, and the absence of testing on real-world communication networks. Furthermore, while exact cooperative game-theoretic solutions are currently computationally demanding, in an era marked by rapid growth in computing power and the development of efficient, lower-complexity algorithms for calculating and approximating the Shapley value (e.g., based on dynamic programming, stochastic sampling, or machine learning techniques), the practical significance and implementation value of the author's theoretical achievement will grow substantially over time.

3. Correctness

The mathematical treatment of the research exhibits a disciplined and coherent progression from the general abstractions of Chapter 3 to the specific linear cost model in Chapter 4, eventually culminating in the capacity-constrained optimizations of Chapter 5. This hierarchical modeling approach allows for the rigorous isolation of factors/variables.

The mathematical foundations of the work are robust. The proofs provided, specifically Theorem 1 (Section 4.5) and game balancedness via linear programming (Section 4.6.1), were found to be algebraically correct. The candidate demonstrates a high level of proficiency in applying these formalisms to network flow problems.

Generally, the mathematical derivations are correct, logically sound, without conceptual or algebraic errors; however some minor algebraic/calculation errors were found. In particular, the label (2.6) is mistakenly applied to two different equations: the betweenness centrality formula on p. 39 and the eigenvector centrality formula on p. 40. Then, on p. 105, in the discussion of admissibility, the threshold for the inequality should be corrected from $x \leq 4$ to $x \leq 3$ to maintain mathematical consistency. In Table 5.21 (p. 155), the marginal contributions for Provider *B*, for two orders (*G*, *R*, *B*) and (*G*, *B*, *R*), are listed as 60, whereas the correct value should be 90. I note that this is a typographical error only, as the final Shapley value vector (45, 75, 45) was calculated correctly based on the intended value.

Furthermore, during the assessment, certain technical nuances regarding game theory concepts were identified that require a clear distinction. It is vital to distinguish between the Bondareva-Shapley theorem, which guarantees a non-empty core for balanced games, and the specific behavior of the Shapley value explored in Chapter 4. In the dissertation, balancedness is repeatedly used to infer that the Shapley value belongs to the core (see, for example, Section 4.6.1, p. 101, lines 3-5). This is false in general: balancedness guarantees only that the core is non-empty. Both proposed Chapter 4 games (v_1 and v_2) are balanced, and their Shapley values payoff vectors are inside the core. That core membership in these instances is a property of the specific data provided rather than a general rule for non-convex games. Next, the Chapter 2 account of superadditivity overstates its implications for incentives to form the grand coalition and stability of allocation payoff vector (Section 2.6.4). While superadditivity suggests that the grand coalition is beneficial, it does not inherently guarantee stability or a non-empty core. The candidate's own counter-example in Figure 2.13 serves as a necessary and correct acknowledgment of this distinction. A notable thematic weakness exists in Section 4.6.2, where the candidate utilizes the concept of "admissibility" without a prior formal definition. This reflects a broader need for more explicit operational criteria regarding the hypotheses presented in Chapter 1, particularly when bridging colloquial intuition and formal game-theoretic requirements. The general hypothesis that the Shapley, Myerson and S-values ensure stability is therefore false without stronger assumptions. In the three-player game (chapter 2, Figure 2.13) all three values yield the symmetric allocations, and every two-player coalition can object.

A key methodological insight arising from the deep dissertation analysis is that several conceptual overreaches in the dissertation derive from conflating the everyday, colloquial meanings of terms—such as "fairness'", "stability", "superadditivity", and "balancedness"—with their strict, technical game-theoretic definitions. Colloquially, if a payoff allocation is deemed "fair", one intuitively assumes that participants have no reason to leave ('stability'); similarly, "superadditivity" intuitively implies that "together is always better", suggesting natural coalitional cohesion. In formal cooperative game theory, however, normative axiomatic fairness (e.g., the Shapley value) and strategic stability (core membership) represent fundamentally distinct mathematical dimensions. While the candidate demonstrates strong proficiency in mathematical proofs and algorithmic execution, the narrative interpretation occasionally succumbs to semantic conflation between colloquial intuition and formal game-theoretic rigor.

Overall, the author demonstrates strong mathematical maturity, formal rigor, and solid analytical skills across all primary theorems and derivations. The minor editorial inaccuracies and conceptual nuances noted above are typical for a dissertation of this breadth and do not in any way diminish the overarching scientific value, technical correctness, or originality of the work.

4. Assessment of Candidate's General Knowledge

The chapters and sections of the dissertation that comprehensively discuss the existing state of knowledge and confirm the candidate's general knowledge in the discipline of Technical Information Technology and Telecommunications are Section 1.1 (Background and Motivation) and the entirety of Chapter 2 (Preliminaries). These sections present a comprehensive review of foundational concepts, mathematical abstractions, and state-of-the-art literature. The candidate therefore displays broad and relevant theoretical knowledge.

In particular, these chapters cover the following areas of Technical Information Technology and Telecommunications disciplines: telecommunications and network management, graph theory and data structures, algorithmic routing and centrality, cooperative game theory and linear optimalization.

Regarding telecommunications and network management, for instance, the analysis covers network architectures (centralized, decentralized, and distributed), software-defined networking (SDN), link-state routing protocols (OSPF, IS-IS), and resource constraints related to bandwidth and capacity.

The topics covered within the area of graph theory and data structures include formal definitions of directed/undirected and weighted/unweighted graphs; graph representations including adjacency matrices, adjacency lists, and incidence matrices; alongside topological metrics such as degree distribution, connectivity, and clustering coefficients.

Regarding algorithmic routing and centrality, for instance, the analysis covers the classical structural centrality measures (degree, closeness, betweenness, eigenvector, Katz, PageRank, edge centrality), as well as shortest-path routing via Dijkstra's algorithm.

Chapter 2 also provides an overview and formalization of cooperative games with transferable utility (TU), covering aspects such as coalition structures, characteristic functions, property analysis (including superadditivity, balancedness, the Bondareva-Shapley theorem, and individual and coalitional rationality—relating to stability criteria). It also discusses the axiomatic and mathematical formulations of well-known solution concepts such as the game core, as well as fair allocation rules, including the Shapley value, the Myerson value (for graph-restricted communication networks), and the S-value (which restrict calculations to permissible coalition-formation chains). Furthermore, this chapter mentions the usefulness of linear programming methods in investigating game balancedness or determination of core constraints. It should be noted that the remaining chapters of the dissertation (chapters 3–5) demonstrate the candidate's practical knowledge of linear optimization issues and their ability to apply tools from cooperative game theory (characteristic functions, marginal contribution, allocations, auctions) to model communication networks.

An added value of the work is that game-theoretic concepts and tools are not presented abstractly in these chapters but rather within the context of communication networks. This lends coherence to the work and facilitates a natural, smooth transition to the subsequent chapters (3–5), where communication networks are modeled specifically using a cooperative game theory approach.

The substantive quality of Chapters 1 and 2 is generally very high. They provide all the necessary fundamentals—covering graph theory, network flow analysis, and cooperative game theory—that enable the development of a coherent framework for managing modern telecommunications networks in subsequent chapters.

The dissertation includes an extensive bibliography of 172 references. It is well-balanced, citing classic foundational works (e.g., Ford & Fulkerson, Shapley, Myerson, Bertsekas) alongside modern research from 2024–2026, including the candidate's co-authored publications.

However, the bibliography is not free of some limitations. Several in-text citations have no matching entry. Specifically, bibliographic entries for the cited works—such as Hellman and Peretz (2018), Alahmed and Tong (2023), Aram et al. (2009), Gemp (2024), Madiman (2008), Saad (2011), Sauras-Altuzarra (2025), and Skiena (1990/2003)—are missing from the list of references. Moreover, there is a problem with the DOI identifiers for bibliographic entries 10 and 112 and the bibliographic entry number 3 on page 167 needs complete publication status.

Finally, the dissertation lacks references to certain works that introduce interesting and significant concepts or issues within the relevant literature. The reader can only access them indirectly through newer publications cited in the dissertation. Specifically, the Bondareva-Shapley theorem is mentioned three times (pp. 54–56) without citations [Bondareva O.N., (1963). Some applications of linear programming methods to the theory of cooperative games. Problemy Kybernetiki. 10: 119–139] and [Shapley, L. S. (1967). On balanced sets and cores. Naval Research Logistics Quarterly. 14 (4): 453–460]. Similarly, Chapter 2 mentions (on pages 50 and 66) the nucleolus—an interesting solution concept from cooperative game theory introduced by David Schmeidler in 1969—as an alternative solution concept for allocating the value generated by cooperation in shortest-path networks. Unfortunately, the dissertation lacks a reference to this work (Schmeidler D. (1969). The nucleolus of a characteristic function game. SIAM Journal on Applied Mathematics, 17 (6): 1163–1170).

Leaving aside minor inaccuracies in these chapters, the broad coverage of literature—combined with a clear and comprehensible presentation of the subject matter, supported by illustrative examples—unequivocally confirms that the candidate possesses the general knowledge required for a doctoral degree in Technical Information Technology and Telecommunications.

Based on the scientific novelty of the proposed framework, the rigorous mathematical proofs, and the candidate's evident mastery of both communication network engineering and economic optimization, I find this work to be a significant contribution to the field. Mr. Rajiansyah has demonstrated the requisite maturity and technical depth to advance to the final stage of the doctoral process.

Furthermore, the analysis contained in the thesis demonstrates the doctoral candidate's profound general theoretical knowledge in the discipline of Technical Informatics and Telecommunications, as well as their ability to conduct independent scientific research.

5. Other notes

The language of the work is clear and understandable. The dissertation is readable and logically structured, moving from foundational theory to increasingly complex specific models.

A critical review of the document confirms notational consistency; that is, the notation remains uniform as the candidate transitions from Chapter 2 (Preliminaries), the general models in Chapter 3 to the capacity-constrained scenarios in Chapter 5. Furthermore, including a list of abbreviations and symbols—along with their descriptions—at the beginning of the work is valuable and facilitates reading.

The work is not free from limitations or minor typos, as was shown in the previous points, but this does not affect the value of the work.

6. Summary

Taking into account the opinions presented in the previous points and the requirements defined by Article 187 of the Act of 20 July 2018—Law on Higher Education and Science (as amended)[1] my assessment of the dissertation in terms of three basic criteria is as follows:

A. Does the dissertation contain an original solution to a scientific problem? (select one option by marking **X**)

X				
Definitely YES	*Probably YES*	*It's hard to say*	*I don't think so*	*Definitely NOT*

B. After reading the dissertation, do you agree that the candidate has general theoretical knowledge in the discipline of Technical Information Technology and Telecommunications?

X				
Definitely YES	*Rather YES*	*It's hard to say*	*I don't think so*	*Definitely NOT*

C. Does the candidate have the ability to conduct research independently?

X				
Definitely YES	*Rather YES*	*It's hard to say*	*I don't think so*	*Definitely NOT*

To summarize, the dissertation offers an original solution grounded in cooperative game theory to a significant scientific problem: the efficient operational management of complex communication networks. It effectively addresses both technical parameters—such as routing optimization and resource constraints—and the economic dimension of equitable profit sharing among service providers. The thesis confirms the candidate's high level of general theoretical knowledge in Technical Information Technology and Telecommunications and showcases his ability to execute independent scientific research. **I hereby conclude that the statutory criteria have been met and recommend admitting the candidate to the public defense.**

[1] http://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20190000276