9 05 2026

Thesis Review: ***On Spreading Phenomena and Influence Maximisation in Multilayer Networks***

Dr. Akrati Saxena
LIACS, Leiden University, The Netherlands

Contribution of the Thesis

The dissertation investigates how **spreading processes (e.g., information, epidemics, influence)** behave in **multilayer networks**, where multiple types of relationships coexist. It focuses on the **influence maximisation problem** and proposes a solution for identifying the most effective nodes (or actors) to initiate diffusion for maximum reach. The work is structured around **seven research gaps**, addressed through a combination of:

- A **generalized modeling framework** for spreading (information diffusion),
- Development of **new metrics** for evaluating spreading effectiveness,
- Creation of **real-world and synthetic multilayer datasets**,
- Evaluation and extension of **heuristic seed selection methods**,
- Introduction of **controllability-based approaches** (minimal dominating set),
- Use of **graph neural networks (TopSpreadersNetwork)** for predicting influential nodes,
- Exploration of **network evolution,** proposing a synthetic generator (mABCD).

Overall, the thesis provides a **multi-paradigm approach** combining network science and machine learning to study diffusion in complex multilayer systems.

Strengths and Contributions

Here, I outline why the thesis meets the requirements for a PhD degree.

1. **Research Work Contribution**
    - This dissertation clearly identifies **seven concrete research gaps**, which is rare at the PhD level.
    - The dissertation addresses both **foundational issues (modelling, metrics)** and **applied problems (algorithms, ML).**

2. **Methodological Breadth**
    - The works presented in the thesis combine classical network science (centrality, heuristics), control theory (dominating sets), machine learning (GNNs), and simulation frameworks. This multi-angle approach adds **depth and robustness**, and shows the multidimensional expertise of the candidate.

3. **Comprehensive Experimental Evaluation**

- The dissertation provides an in-depth, large-scale evaluation across all papers, including spreading models and multiple networks.

4. **Data and Reproducibility**
   - Publishes **datasets, code, and tools**, addressing a major gap in network science.
   - Provides **longitudinal real-world data**, which is scarce in this domain.

5. **Future Scope**
   - The dissertation opens up several directions for future research. For instance, incorporating fairness constraints into influence maximisation and developing more scalable graph neural network models remain important areas to explore. It will be interesting to know how to extend current models to incorporate fairness constraints, ensuring balanced influence spread across different groups and avoiding bias amplification. Additionally, it will be interesting to discuss how one can develop lightweight graph neural network models that can handle large-scale multilayer networks with reduced computational cost. One can also consider evolving network structures and adaptive behaviors of nodes to analyze how these dynamic changes impact influence maximization. It will be interesting to discuss these questions during the defense. Overall, the work makes a significant contribution and provides a strong foundation for subsequent research.

Overall Assessment

This is a **technically strong and well-scoped PhD thesis** with clear contributions in the multilayer networks and influence maximisation. The work stands out for its **completeness** while emphasizing **reproducibility and evaluation, significantly contribiuting to the field of computer science**. Taking the above into account, I conclude that the reviewed work meets the requirements set for doctoral dissertations. Therefore, **I recommend that this dissertation be accepted and that Mr. Michał Czuba, M.Sc. Eng., be admitted to the public defense.**

Taking into account the high quality of the doctoral dissertation, **I would like to recommend the thesis for distinction.**

Additional Information

I have added my remarks in blue color:

1. With reference to the cover letter, the Chairman requests the following: "whether the dissertation:

   1. presents the general theoretical knowledge of the candidate in the considered field (information and communication technology), as well as whether the candidate can conduct scientific work independently,

      The thesis work shows that the candidate has good knowledge in the field, and the candidate can conduct scientific research work independently.

   2. contains an original solution of a scientific problem."

      The thesis work provides original solutions to the scientific problems that were identified as a research gap by the candidate.

2. The Professor requests that you include critical remarks regarding the dissertation in your review. Alternatively, please provide information if you have no such critical comments at all.
I do not have any critical remarks that require any changes or additional results to be added to the thesis. I had some questions that will be interesting to discuss during the defense and mentioned them in the future scope.

3. The Professor also requests comments and an evaluation of each individual publication.
I have added comments and evaluations for each individual publication below:
P1: Simulating Spreading of Multiple Interacting Processes in Complex Networks – This work proposes a computational framework, called *Network Diffusion*, for simulating multiple interacting spreading processes in single and multilayer networks. It fills an important gap by providing a model for competing, supporting, and mixed spreading dynamics. The work provides a clear and flexible modelling framework with strong practical usability through open-source implementation, examples, and reproducible experiments. It also introduces a general way to represent interactions between multiple spreading processes.

P2: Network Diffusion Framework to Simulate Spreading Processes in Complex Networks – This work introduces the *Network Diffusion* framework, a tool for simulating spreading processes such as epidemics, information diffusion, and influence spread in temporal and multilayer networks. This is also a good extension based on P1. The paper includes four case studies showing the impact of sanitary measures on the spread of COVID-19, the comparison of information diffusion on two temporal network models, and the effectiveness of seed selection methods in the task of influence maximisation in multilayer networks. The contribution advances the field by proposing a flexible framework that can be further used to analyse spreading processes in complex temporal and multilayer networks, while also supporting reproducible and extensible research in network science.

P3: Peer Interaction Dynamics and Second Language Learning Trajectories During Study Abroad: A Longitudinal Investigation Using Dynamic Computational Social Network Analysis – This work studies how peer interaction networks influence second language learning during study abroad using computational social network analysis. It provides a longitudinal analysis of how students' communication patterns, social positions, and language development change over time. A major strength of the work is the use of a complete social network instead of only individual-level interactions, which gives a more realistic understanding of student communication patterns. The study also combines language learning research with computational network analysis and tracks changes across multiple time points. This also strengthens the capabilities of the PhD candidate to collect real-world data, formulate analytical methodologies, and address real-world problems using interdisciplinary computational and social network analysis approaches.

P4: Rank-refining seed selection methods for budget constrained influence maximisation in multilayer networks under linear threshold model – This work studies budget-constrained influence maximisation in multilayer networks using the Linear Threshold Model and evaluates multiple seed selection methods under different network conditions. A major strength of the work is the extensive experimental evaluation across many real-world and synthetic multilayer networks using different spreading settings and budgets. The study is also systematic and reproducible, with open-source implementation and detailed methodological analysis. This work advances understanding of how spreading behaviour changes across different multilayer network structures and diffusion settings. It also strengthens the PhD student's ability to formulate complex network science problems, design large-scale computational experiments, analyse multilayer diffusion processes, and share open source research code to advance the field.

P5: Applicability of the minimal dominating set for influence maximization in multilayer networks – This work uses the Minimal Dominating Set (MDS) to provide a solution for the influence maximization problem in multilayer networks. The study shows that MDS can improve information spreading under certain conditions, especially in scale-free networks, low activation thresholds, and AND-type spreading dynamics. The strengths of this work are the use of the combination of control theory and influence maximization, and extensive experimental evaluation on both synthetic and real-world multilayer networks under many spreading conditions. In the future, it will be important to see how fairness can be incorporated in such solutions for fair influence maximization.

P6: Identifying Super Spreaders in Multilayer Networks – This work proposes a GNN-based model called TopSpreadersNetwork to identify seed nodes in multilayer networks. It also introduces a new dataset and a ranking-based framework for studying information diffusion across complex multilayer systems. The model can be generalized to unseen real-world networks of different sizes and structures, which is an additional benefit as compared to classical methods. This helps the PhD candidate strengthen his skills in applying machine learning and AI techniques for network science problems. In future work, one can work on extending this framework to dynamic networks where connections change over time.

P7: Multilayer artificial benchmark for community detection (mABCD) – This work introduces mABCD, a new synthetic benchmark model for generating realistic multilayer networks with community structures. The model is flexible, scalable, and allows researchers to control both layer-specific properties and correlations between layers, making it useful for studying complex real-world systems. Another key strength is that the model can generate multilayer networks much faster than existing approaches while still preserving realistic network properties. This work provides researchers with a realistic and efficient benchmark for testing multilayer network algorithms in a controlled setting. This work will help improve research in network science domains, such as community detection and information spreading, making experiments more reproducible and comparable across studies. Overall, it was a much-needed model in the domain. It shows the theoretical as well as modeling skills of the PhD candidate.