Epidemic Spread on Weighted Networks

Final Project Proposal - Complex and Social Networks (CSN)

Tim Wolfgang Helmut Schwabe, Odysseas Kyparissis

December 14, 2023

Facultat d'Informàtica de Barcelona (FIB)
Universitat Politècnica de Catalunya (UPC) - BarcelonaTech

Contents

1 Domain, background

The spread of epidemics on networks is a crucial aspect in understanding infectious diseases. In this project, we will focus on enhancing the realism of epidemic spread models by incorporating (edge) weighted networks. The significance of weighted networks lies in representing heterogeneous contacts among individuals, such as the number of sex acts in the case of sexually transmitted diseases. To achieve this, we draw inspiration from existing models and extend them to account for weighted interactions.

Two primary models, SIS (Susceptible Infectious Susceptible) and SIR (Susceptible Infectious Recovered), will be considered to explore the dynamics of epidemic spread on weighted networks. We aim to estimate key epidemiological variables, including the basic reproductive ratio R, which plays a crucial role in understanding the severity of an epidemic.

The foundation for this research is laid in the works of Christel Kamp, Mathieu Moslonka-Lefebvre, and Samuel Alizon [2] and Pastor-Satorra et al. [4], providing insights into epidemic spread on weighted networks. Additional literature exploration will contribute to a comprehensive understanding of the topic.

2 Aim(s) of the research

The primary aims of this research project are as follows:

1. **Model Development:** Develop a model for epidemic spread on weighted networks, incorporating the dynamics of SIS and SIR models.
2. **Parameter Estimation:** Estimate key epidemiological variables, particularly focusing on the basic reproductive ratio R, to quantify the severity of the epidemic.
3. **Literature Comparison:** Compare the proposed model against existing models to evaluate its realism and effectiveness in capturing the complexities of epidemic spread on weighted networks.

3 Hypotheses to be tested

The main working hypothesis for this project is the following:

- In the SIS model, by applying an argument similar to Chakrabarti et al. [1] for unweighted networks, we hypothesize that the epidemic threshold for the weighted case must be proportional to the inverse of the eigenvalue of the weights adjacency matrix. This hypothesis will be rigorously proven and tested through simulations.

The next subsection, includes information about the generation of the network's weights corresponding to the sexual interactions of the individuals.

3.1 Data generation for weighted networks

To rigorously test the hypotheses outlined above, it is essential to accurately represent the weighted interactions among individuals within the network. We will employ a data generation process to simulate the weights on the network edges, allowing us to explore various scenarios and distributions that capture the diverse nature of sex interactions in real-world settings.

3.1.1 Simulation of edge weights

To simulate the weights on the edges of the network, we will utilize different probability distributions, reflecting the variability in contact strengths observed in social networks and other contexts. Some ideas about distributions to be considered:

1. **Normal Distribution:** Weights could be generated from a normal distribution, introducing a level of randomness that can represent typical social interactions.

2. **Power-law Distribution:** To analyze the scale-free nature of social networks, weights can be generated according to a power-law distribution, capturing the presence of a few highly connected individuals.

3. **Exponential Distribution:** The exponential distribution can be considered to model interactions where the majority of weights are relatively low, but there is a tail of higher weights.

4. **Custom Distribution:** Additionally, an idea is to explore a custom distribution tailored to our specific research context, designed based on insights from the literature and the characteristics of weighted interactions in the context of infectious disease spread.

By simulating weights from these diverse distributions, our research aims to capture the range of contact strengths in realistic social networks. This approach enables us to assess the impact of different weighting structures on epidemic dynamics, contributing to a more comprehensive understanding of infectious disease spread on weighted networks.

4 Theoretical framework

The theoretical framework for this research is rooted in the field of network science, specifically focusing on the study of epidemic spread on weighted networks. Drawing on graph theory and the emerging field of network science, we aim to build a comprehensive understanding of the dynamics of infectious diseases in complex network structures.

Chapter 17 of Newman's book with title ***Networks*** [3], together with the works of Christel Kamp, Mathieu Moslonka-Lefebvre, Samuel Alizon [2] and Pastor-Satorra et al. [4] provide the theoretical foundation for this project. The theory of random networks will also be instrumental in developing a robust model for epidemic spread on weighted networks.

5 Methods

The methodology for this project involves a combination of literature review, model development, and computational simulations. The steps are outlined below:

1. **Literature Review:** Thoroughly study the works mentioned in Section 4, along with additional relevant literature on epidemic spread on weighted networks.

2. **Model Implementation:** Implement the proposed epidemic spread model on weighted networks based on the insights gained from the literature review. Extend the SIR model treated in the paper by Kamp et al. [2] to incorporate the dynamics of the SIS model.

3. **Simulation and Analysis:** Conduct computer simulations to explore the dynamics of the developed model. Special emphasis will be given to testing the hypothesized relationship between the epidemic threshold and the inverse of the eigenvalue of the weights adjacency matrix.

4. **Parameter Estimation:** Estimate key epidemiological variables, including the basic reproductive ratio R, through simulations and analytical methods.
5. **Comparison with Existing Models:** Compare the performance and realism of the developed model against existing models, particularly those discussed in the literature.

References

[1] Deepayan Chakrabarti et al. "Epidemic thresholds in real networks". In: *ACM Transactions on Information and System Security (TISSEC)* 10.4 (2008), pp. 1–26.

[2] Christel Kamp, Mathieu Moslonka-Lefebvre, and Samuel Alizon. "Epidemic spread on weighted networks". In: *PLoS computational biology* 9.12 (2013), e1003352.

[3] Mark Newman. *Networks*. Oxford university press, 2018.

[4] Romualdo Pastor-Satorras et al. "Epidemic processes in complex networks". In: *Reviews of modern physics* 87.3 (2015), p. 925.