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Preventive behavioural responses and information dissemination in network epidemic models

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Abstract— Human behavioural responses have an important impact on the spread of epidemics. To deal with them, some epidemic models consider that individuals are aware of the risk of contagion and adopt preventive responses when they learn about the existence of the disease. If awareness is assumed to be transmitted from individual to individual, the information dissemination can be thought to spread over a second network where links are defined according to a certain type social relationship (friends, acquaintances, etc.), with the same set of nodes as the contact network. Here we present a simple model for epidemic spreading with awareness defined on a two-layer network which includes the overlap between these two layers as a parameter. This formulation leads to an expression of the epidemic threshold as a function of the network overlap.

Keywords: Epidemic modelling, multilayer networks.

1 Introduction

Human behavioural responses have an important impact on the spread of epidemics. One way to include them into epidemic models is to consider individuals who are aware of the risk of contagion and adopt preventive responses when they get informed about the existence of the disease. Some models include a new class of individuals, the so-called aware or alerted ones, and derive the corresponding equations for the transmission of the disease and recovery (see, for instance, [7] and references therein). More sophisticated models consider specific features of the information transmission process. For example, in contrast to disease transmission, the quality of information passed on to other people decreases at each transmission event. This leads to more complex models with several classes of aware individuals (see [3]). On the other hand, the routes of information transmission do not need to be the same as those for the spread of a disease. In this case, information dissemination is modelled by means of a second network, with the same set of nodes as the contact network but with a distinct set of links, over which information spreads.

In a more general context, the simultaneous spread of awareness and infectious diseases is an example of interacting spreading processes taking place on multilayer networks. Other examples are competitive viruses propagating in a host population where each virus has different routes of transmission, i.e., a distinct network for propagation (see [4, 11]). In such an instance, the interaction among virus species is determined by the type of competition existing between them (exclusive, reinforcing, weakeing, etc.) when they coincide in the same host. A challenging issue related to these processes is to elucidate the effect of the cross-layer interrelation on the dynamics of simultaneous propagation of contagious agents. Some analytical results relating different features of the adjacency matrices of a two-layer network have been recently obtained in [11].

Following the studies of the impact of network overlap on the coexistence of competing viral agents in [3, 4, 9], we derive a simple mean-field epidemic model defined on a two-layer network where the overlap between the two layers appears as a parameter of the model equations. This fact allows to express the basic reproduction number R_0 as a function of the overlap of the two networks and, hence, to derive a simple analytical expression of the epidemic threshold which involves the network overlap. Certainly, the overlap between two layers offers an incomplete description of the cross-layer interrrelation but, in addition to degree-degree correlations between layers, is a basic statistical descriptor of its topology. Finally, model's predictions are tested against the output of stochastic simulations of epidemic spreading carried out in continuous time on partially overlapped networks generated using the so-called network configuration model and a cross-rewiring algorithm.

2 An SIS epidemic model defined on a two-layer network

As usual in epidemic modelling, we describe the spread of infectious diseases on populations by classifying their individu-

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