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A multilayer temporal network model for STD spreading accounting for permanent and casual partners

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Sexually transmitted diseases (STD) modeling has used contact networks to study the spreading of pathogens. Recent findings have stressed the increasing role of casual partners, often enabled by online dating applications. We study the Susceptible-Infected-Susceptible (SIS) epidemic model –appropriate for STDs– over a two-layer network aimed to account for the effect of casual partners in the spreading of STDs. In this novel model, individuals have a set of steady partnerships (links in layer 1). At certain rates, every individual can switch between active and inactive states and, while active, it establishes casual partnerships with some probability with active neighbors in layer 2 (whose links can be thought as potential casual partnerships). Individuals that are not engaged in casual partnerships are classified as inactive, and the transitions between active and inactive states are independent of their infectious state. We use mean-field equations as well as stochastic simulations to derive the epidemic threshold, which decreases substantially with the addition of the second layer. Interestingly, for a given expected number of casual partnerships, which depends on the probabilities of being active, this threshold turns out to depend on the duration of casual partnerships: the longer they are, the lower the threshold.

The rising number of infected individuals with sexually transmitted diseases (STD) is a significant concern for public health. It is estimated there are one million new cases of curable STDs acquired each day globally[1]. Specifically, the reports from the Centers for Disease Control and Prevention (CDC) in the U.S. show a dramatic increase in new infections from chlamydia, gonorrhea, and syphilis since 2013. Although common STDs can be treated with antibiotics, antibiotic resistance can exacerbate the situation. It is well known that the structure of the sexual network plays a major role in the spread of STDs[2,3]. Indeed, with the increasing trend in online dating, sexual networks become more complex and dynamic. For example, a recent study indicates a relationship between using an online dating application and having had five or more previous sexual partners in young adults[4]. To capture the effect of the sexual network and pair formation on the spread of STDs, researchers have developed various mathematical models. However, these models do not consider the heterogeneity in link formation at the individual level because their formulation is based on a mean-field description at the level of pairs[5,6] or on a statistical description of the sexual network[7]. Individual-based stochastic models have been traditionally developed when a more detailed description of individuals is considered in pair formation, including individual age, different infectious periods, and concurrent partnerships[3,8,9].

In this paper, we develop a model that incorporates the effect of each individual in the sexual network on the spread of STDs. The susceptible-infected-susceptible (SIS) model over a complex network is a mathematical approach for describing the spread of a pathogen in a population with heterogeneous connectivity among individuals[10–13]. In this context, a stochastic approach is suitable because the description of the spreading process includes a degree of uncertainty at the individual level that is not present when one assumes fully mixing among members of the populations (compartmental models). Such an uncertainty can be quantified using stochastic individual-based models to obtain a distribution of outcomes. Indeed, the analysis of the SIS model over static networks has clarified the role of network structure in the emergence of the endemic state[3]. This result, in turn,

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