Small-World Network Models of Epidemic Spread for Bio-Defense Applications

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OBJECTIVE

We discuss dynamic small-world network models to simulate contagious disease spread in urban populations. The model attempts to replicate the dynamics inherent in large scale, networked agent-based epidemic simulations while remaining computationally tractable and applicable to scenarios where detailed knowledge of the transportation or social network structure is non-existent. We have calibrated and tested this model using simulated epidemics of smallpox and pneumonic plague derived from a biologically-based mathematical model developed by Sandia National Laboratories[2]. The technique is applicable in a biosurveillance context to infer the unobserved infection rate given observations of an ongoing "partial" epidemic in a given population.

BACKGROUND

Network models have received much attention in recent years as realistic representations of a wide variety of natural phenomena[2]. A subset of these models are referred to as "small-world" because of the presence of long-range links in an underlying local network structure. The presence of the long-range links has the effect of introducing a short path length between widely separated regions in the network, and produces a wide variety of interesting effects that have been well studied theoretically. Several studies have attempted apply small-world networks to numerical studies of epidemic data such as the SARS outbreak[3] and seasonal flu[4]. These studies have been based on limited data and have used various approximation schemes to simplify the procedure for fitting the epidemic model to data. The potential of the small-world models for realistically simulating epidemics has not been fully explored.

METHODS

ARA is currently investigating the use of a dynamic, small-world network model to simulate contagious disease spread in realistic models of urban populations. Small-world networks are attractive models to use for simulating contagious disease because realistic models of human transportation and social contacts have shown to have a small world structure[5]. For a particular disease and affected population, our model has two free parameters which are related to network structure of the population. We have automated the determination of these parameters for smallpox and plague using epidemic curves provided by Sandia National Laboratories from a full scale, agent-based simulation of disease spread in the Portland, Oregon area. The simulated epidemic data makes it feasible to study the usefulness of the model in describing epidemics with widely varying initial conditions. In this paper we discuss our technical approach to fitting small-world network models to calculated epidemic data, computational requirements, and potential future studies.

RESULTS

We present results showing model parameters calculated for different diseases and initial conditions. We demonstrate how the determined model parameters can potentially provide realistic predictions for other scenarios with different population structure or different initial number initially infected. The limitations of the small world network for modeling other scenarios are discussed.

CONCLUSIONS

Small-world networks provide a useful model for calculating epidemic outbreaks in urban populations. The model has the benefits of a simulation without the computational complexities and data modeling requirements of realistic social contact models. Countermeasure effectiveness studies are an easy extension to the model. We have developed techniques for rapidly calculating model parameters based on epidemic curves, studied the variation of the model parameters with population structure and initial conditions, and demonstrated the range of validity of the small world model for calculations of this type.

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