



Suppressing traffic-driven epidemic spreading by adaptive routing strategy



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ABSTRACT

The design of routing strategies for traffic-driven epidemic spreading has received increasing attention in recent years. In this paper, we propose an adaptive routing strategy that incorporates topological distance with local epidemic information through a tunable parameter h . In the case where the traffic is free of congestion, there exists an optimal value of routing parameter h , leading to the maximal epidemic threshold. This means that epidemic spreading can be more effectively controlled by adaptive routing, compared to that of the static shortest path routing scheme. Besides, we find that the optimal value of h can greatly relieve the traffic congestion in the case of finite node-delivering capacity. We expect our work to provide new insights into the effects of dynamic routings on traffic-driven epidemic spreading.

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1. Introduction

Epidemic spreading [1–14] and traffic dynamics [15–21] on complex networks [22–24] have attracted much attention in the past decade. For a long time, the two types of dynamical processes have been studied independently. However, epidemic spreading often depends on traffic transportation. For example, a computer virus can spread over Internet via data transmission. Another example is that air transport tremendously accelerates the propagation of infectious diseases among different countries.

The first attempt to incorporate traffic into epidemic spreading is based on metapopulation model [25]. This framework describes a set of spatially structured interacting subpopulations as a network, whose links denote the traveling path of individuals across different subpopulations. Each subpopulation consists of a large number of individuals. An infected individual can infect other individuals in the same subpopulation. The metapopulation model is often used to simulate the spread of human and animal diseases (such as SARS and H1N1) among different cities. In a recent work, Meloni et al. proposed another traffic-driven epidemic spreading model which can be applied to study the propagation of computer virus on the Internet [26]. In Meloni model, each node of a network represents a router on the Internet and the epidemic can

spread between nodes by the transmission of packets. A susceptible node will be infected with some probability every time it receives a packet from an infected neighboring node.

Meloni model has received increasing attention in recent years [27–32]. It has been found that the routing strategy can greatly effects epidemic spreading [33,34]. Three routing algorithms have been used in Meloni model. The first is the shortest-path routing algorithm. The second is the local routing protocol [35], in which each node does not know the whole network's topological information and the packet is forwarded to a neighboring node i with a probability that is proportional to the power of i 's degree. The third is the efficient routing protocol [36], in which each node in a network is assigned a weight that is proportional to the power of its degree and The efficient path between any two nodes corresponds to the route that makes the sum of the nodes' weight (along the path) minimal.

All the above routing strategies are based on the network structure and packets follow the fixed routes for a given network. In this paper, we propose an adaptive routing strategy that integrates topological distance with local epidemic information through a tunable parameter h . In the adaptive routing strategy, a packet can timely adjust its route according to the epidemic information of its neighbors. Interestingly, we find that there exists an optimal value of h , leading to the maximal epidemic threshold.

The paper is organized as follows. In Section 2, we formalize the problem by introducing the adaptive routing strategy into traffic-driven epidemic spreading. In Section 3 and Section 4, we present

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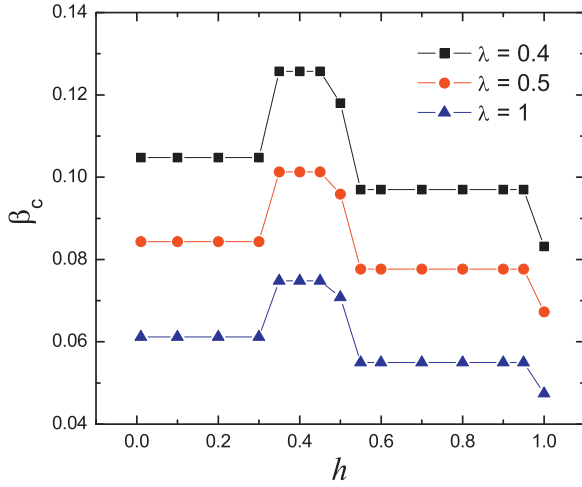


Fig. 1. The epidemic threshold β_c as a function of the routing parameter h for different values of the packet-generation rate λ . The node-delivering capacity is infinite.

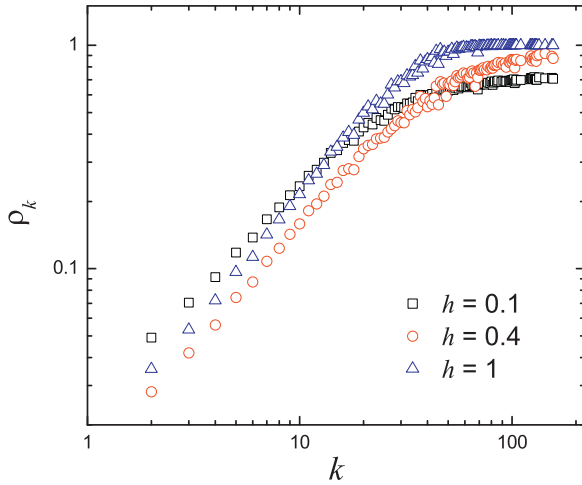


Fig. 2. The density of infected nodes ρ_k as a function of the degree k for different values of the routing parameter h . The packet-generation rate $\lambda = 0.5$ and the spreading rate $\beta = 0.13$. The node-delivering capacity is infinite.

the results for infinite and finite node-delivering capacity respectively. Finally, we give a conclusion in Section 5.

2. Model

Following the work of Meloni et al. [26], we incorporate the traffic dynamics into the classical susceptible-infected-susceptible model [37] of epidemic spreading as follows.

(i) *Adaptive routing protocol.* In a network of size N , at each time step, λN new packets are generated with randomly chosen sources and destinations (we call λ as the packet-generation rate), and each node can deliver at most C packets towards their destinations. To deliver a packet to its destination, a node performs a local search within its neighbors. If the packet's destination is found inside the searched area, it will be delivered directly to the destination. Otherwise, the packet is forwarded to a neighboring node i toward its destination j with the smallest value of effective distance, denoted by

$$d_{eff}^{ij} = h \cdot D_{ij} + (1 - h) \delta_i, \quad (1)$$

where h is the routing parameter ($0 \leq h \leq 1$), D_{ij} is the topological distance between nodes i and j , and $\delta_i = 1$ ($\delta_i = 0$) if node i is infected (uninfected) in the previous time step.

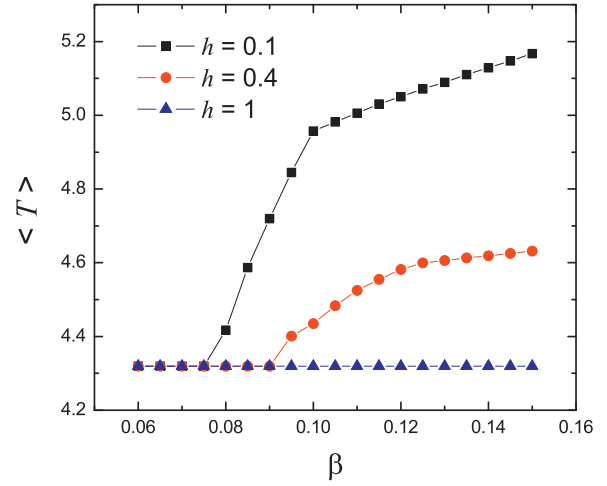


Fig. 3. The average traveling time of a packet $\langle T \rangle$ as a function of the spreading rate β for different values of the routing parameter h . The packet-generation rate $\lambda = 0.5$. The node-delivering capacity is infinite.

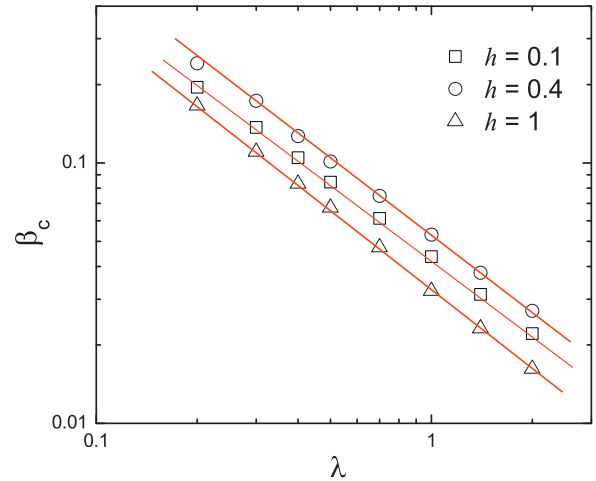


Fig. 4. The epidemic threshold β_c as a function of the packet-generation rate λ for different values of the routing parameter h . The slopes of the fitted lines are about -1 . The node-delivering capacity is infinite.

It is worth noting that when $h = 1$, the adaptive routing recovers to the traditional shortest path routing. Once a packet reaches its destination, it is removed from the system. The queue length of each node is assumed to be unlimited and the first-in-first-out principle holds for the queue.

(ii) *Epidemic dynamics.* After a transient time, the total number of delivered packets at each time will reach a steady value, then an initial fraction of nodes ρ_0 is set to be infected (e.g., we set $\rho_0 = 0.1$ in numerical experiments). The infection spreads in the network through packet exchanges. Each susceptible node has the probability β of being infected every time it receives a packet from an infected neighbor. The infected nodes recover at rate μ (we set $\mu = 1$ in this paper).

In the following, we carry out simulations systematically by employing traffic-driven epidemic spreading on the Barabási-Albert (BA) scale-free networks [38]. The size of the BA network is set to be $N = 2000$ and the average degree of the network is $\langle k \rangle = 4$. Each data point results from an average over 30 different realizations.

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