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A hybrid routing model for mitigating congestion in networks

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ABSTRACT

Imbalance between fast-growing transport demand and limited network supply has resulted in severe congestion in many transport networks. Increasing network supply or reducing transport demand could mitigate congestion, but these remedies are usually associated with high implementation cost. Combining shortest path (SP) routing and minimum cost (MC) routing, we developed a hybrid routing model to alleviate congestion in networks. This model requires only a small fraction of the total number of agents to use MC routes, and effectively mitigates congestion in networks under homogeneous or heterogeneous transport demand, offering new insights for improving the efficiency of practical transport networks.

1. Introduction

Transport networks, from airline networks [1,2], road networks [3–5] to power-grids [6], the Internet [7,8], and social networks [9–11], play essential roles in our modern society. As such, their efficiency is of great significance, and has drawn wide-spread attention from both scientific and engineering fields [12–14]. Congestion, which is the most common reason for the inefficiency of transport networks, is fundamentally caused by imbalance between network supply [5,13] and transport demand [15,16]. Examples include vehicle congestion on roadways and packet queuing in the Internet. To mitigate congestion, methods for improving network topology have been studied to better accommodate time-variant and usually fast growing transport demand [5,13]. However, given limitations in resources and response time, modification of network structure is usually difficult or even infeasible in some situations. On the other hand, intelligent routing agents from origins to destinations do not modify the structure of networks or reduce transport demand, and thus serve as a feasible and important means for mitigating congestion in many transport networks.

The most fundamental routing method is based on the shortest path algorithm proposed by Dijkstra [17]. However, while the shortest path strategy minimizes the path length, it may result in severe congestion at hubs. To solve this problem, routing methods that minimize the sum of the degree (or the logarithm of degree) of nodes along the path have been proposed [18,19]. Researchers have further built functions between transport volume and node degree. By tuning the function parameters, transport volume has been homogeneously distributed at each node, though the transport time is increased [20]. Sreenivasanet al. [21] also proposed a method to avoid hub congestion. The method first removes hubs, splits a network into disconnected clusters, and calculates the shortest paths for nodes within each cluster. Next, the method returns the removed hubs and calculates the shortest paths for those node pairs that were not preceded. Node betweenness has also been employed to mitigate congestion in networks. Bogdan [22] balanced traffic in a network by minimizing the largest node betweenness. José et al. [23] investigated means of effectively mitigating congestion while simultaneously maintaining negligible changes in path lengths. Moreover, the usage rate of nodes has been accounted for in the deployment of efficient

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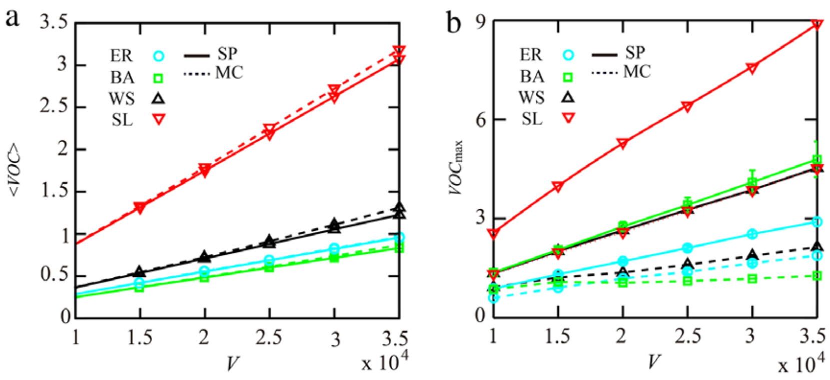

Fig. 1. Quantifying the congestion of links in random networks (blue circles), scale-free networks (green squares), small-world networks (black triangles), and a square lattice (red triangles). The average and maximum volume over capacity (*VOC*) under different transport volumes *V* are depicted in (a) and (b), respectively. Solid lines and dashed lines respectively discriminate the results obtained using SP routing and MC routing. For random networks (ER), scale-free networks (BA), and small-world networks (WS), a symbol represents the average over 10 independent simulations, and an error bar represents a 95% confidence interval. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

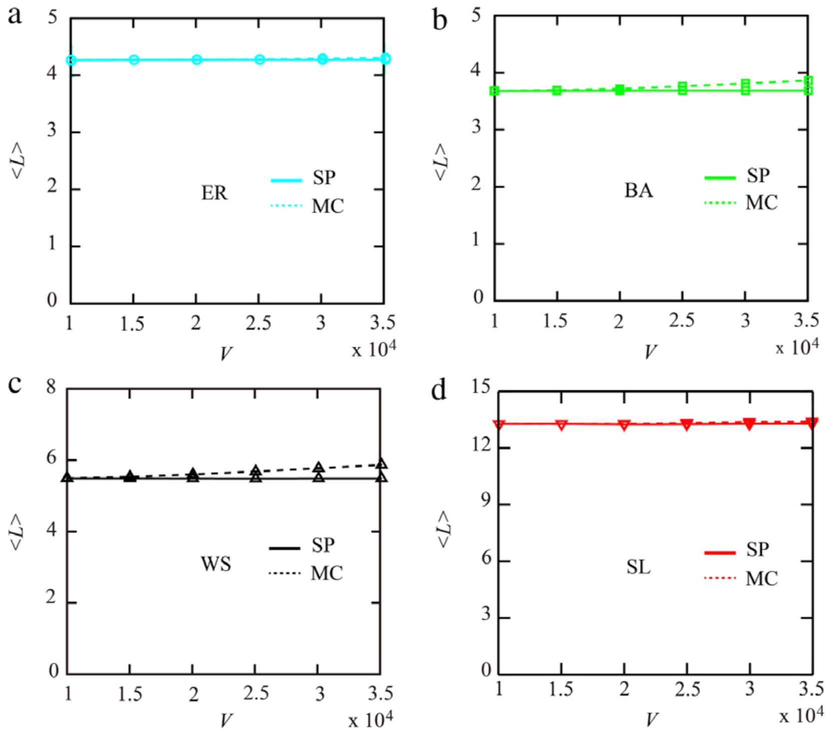

Fig. 2. Average path length $\langle L\rangle$ of random networks (a), scale-free networks (b), small-world networks (c), and a square lattice (d) under different transport volumes. Solid lines and dashed lines represent the results obtained using SP routing and MC routing, respectively. In (a), (b), and (c), a symbol represents the average over 10 independent simulations, and an error bar represents a 95% confidence interval.

routing algorithms [24,25]. Effective distance, which simultaneously takes into account the queuing time of a node's neighbors and the shortest distances from the neighbors to the destination, was employed in some routing models [26,27]. Global queuing time information has also been employed to develop a routing model [28]. Although the use of global information can achieve better routing performance, the method comes with a higher computing cost. Finally, information concerning dynamical queue length, dynamical betweenness centrality, node degree, and path length have been combined to deploy efficient routing models [29–31]. Researchers have found that, when the network is highly congested, it is more important to consider local information rather than global information [32].

The forgoing discussion indicates that former methods for improving the transport performance of networks have been mostly based on network topology (i.e., node degree) or dynamical network conditions (i.e., queue length). In the present study, we consider a routing model based on the agents that use the networks. By targeting agents that suffer heavy congestion, we develop a hybrid routing model that can effectively reduce congestion with a cost of only a slightly increased