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Efficient routing on two layer degree-coupled networks

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HIGHLIGHTS

- We model a two-layer degree-coupled network.
- We investigate the variation of traffic capacity with coupling randomness.
- Traffic capacity decreases with the coupling randomness.
- Highest node betweenness decreases with the coupling randomness.
- Fraction of repeated node paths on central nodes increases with coupling randomness.

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ABSTRACT

Traffic dynamics of multiplex networks is one of the new research topics since many systems are proved not to be composed of only a single layer network. Here we focus routing strategies on a two layer degree-coupled network that is composed of a logical layer network and a physical layer network. In this paper, three routing strategies are proposed. Increasing coupling randomness between inter-layer nodes decreases the traffic capacity of the system, which is the result of increase of repeated routing on central nodes. Further, we show that a weighting logical layer network cannot enhance traffic capacity significantly, while avoiding passing through those heavy traffic nodes could notably promote traffic capacity than the performance of a similar strategy in a traditional one layer network.

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1. Introduction

Traffic dynamics of complex systems has been a hot research topic for a long time [1–6]. The processes such as information packet transport on the Internet, people traveling to their destination by various transport tools, and mass transfer by chemical reactions in a cell are all real dynamics traffic processes [7–9]. Bearing heavy traffic load or limited individual delivery ability, real complex systems often suffer from traffic jamming or congestion [10,11]. Therefore, the studies of recovering the rule of traffic flow phase transition from free-flow to congestion and working out optimal strategies to increase traffic capacity are many related works heading for Ref. [12,13]. These studies include shortest path routing strategy [14,15], efficient shortest path routing strategy by adding node degree impaction [5], shortest path routing strategy considering the waiting time on neighbor nodes [16,8], global routing strategies [17], routing strategy combining both static and dynamic information routing [18] and so on.

However, these routing strategies are all applied on single layer networks. As a matter of fact, in real world, many systems are discovered to be composed of a couple of layer networks interacting with each other [19–23], which bring

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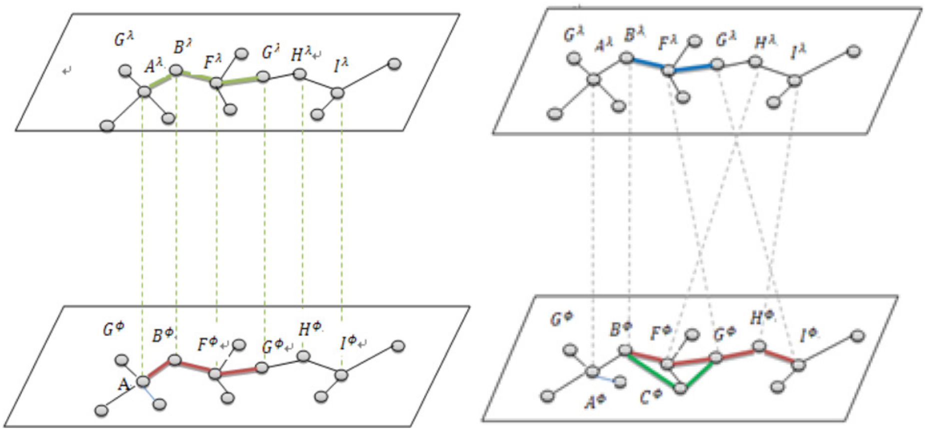

Fig. 1. Illustration of the two layer degree-coupled network model. The left picture is the initial case that the two layer networks' nodes are coupled one-by-one. The right picture shows that a portion of nodes on each two layer network are coupled random. The logical edge $e(F^{\lambda}, G^{\lambda})$ corresponds to its physical shortest path $G^{\emptyset}$–$H^{\emptyset}$–$I^{\emptyset}$. The physical path $B^{\emptyset}$–$F^{\emptyset}$–$G^{\emptyset}$–$H^{\emptyset}$–$I^{\emptyset}$ corresponds to its logical path B^{λ}–F^{λ}–G^{λ}. In logical weighted traffic-awareness shortest path routing strategy, packets go through $B^{\emptyset}$–$C^{\emptyset}$–$G^{\emptyset}$–$H^{\emptyset}$–$I^{\emptyset}$ other than $B^{\emptyset}$–$F^{\emptyset}$–$G^{\emptyset}$–$H^{\emptyset}$–$I^{\emptyset}$.

out more complex topology properties and more complex dynamics than those in single layer network systems. Live issues on multiplex systems, such as the robustness, frangibility, diffusion dynamics and evolution are addressed [24–28]. Recently more research works have paid attention to traffic dynamics of multiplex networks [29–34]. The authors of Ref. [30] extract the physical structure and network of traffic flow from timetables of public mass transport systems into a two layer network where the lower layer is physical infrastructure and the upper layer represents the traffic flows. In Ref. [31], the authors proposed a traffic model on a two layer networks. They found that networks' traffic capacity is related to the topology of each layer network. In Ref. [33], the author investigates transport on a two coupled spatial network and points out that as the coupling increases, the length of the average shortest path packets pass by decreases, but the optimization of such a system is sensitive to the randomness of the chosen source and sink. The authors of Ref. [34] study the traffic capacity on a two layer networks coupled by wireless and wire network. They managed to iterate the highest betweenness search process to route packets optimally.

As the large scale of most networks, nodes are always impossible to know shortest paths to all their destinations, that is, nodes only know a portion of paths. On the other hand, nodes' knowledge of shortest paths is different from one another. For instance, nodes having more connections know shortest paths more than those having fewer connections; the important nodes, like router or switcher nodes on the Internet, or hub or center city in urban transport networks can reach more areas of the networks than other common nodes. Inspired by this real world situation, in this work, we give an insight into traffic dynamics in this case and show interesting results which we believe might be typical in all of this class. First, we abstract network topology and the shortest paths pattern on it into two layer networks. The lower layer network is called physical network and the upper layer is called logical network. The two layer networks are identical and nodes on each layer network are coupled one-by-one initially. Then we change this one-by-one coupling to random coupling and investigate how the traffic capacity of this two layer degree-coupled network varies.

The organization of this paper is as follows. The two layer degree-coupled network model will be introduced in Section 2. Based on this model, we propose three related routing strategies in Section 3. Results about the traffic capacity and its interpretation will be shown in Section 4. Finally, we give our conclusion on traffic dynamics of this two layer degree-network in Section 5.

2. Two layer network model

We generate two identical layer networks as BA scale-free networks [35]. The lower layer network is the physical network $G^{\emptyset} = (V^{\emptyset}, E^{\emptyset})$ representing the topology of the network. The upper layer network is the logical network $G^{\lambda} = (V^{\lambda}, E^{\lambda})$ representing the shortest paths pattern [29] on the physical network. The size of a single layer network is $N = 1000$. Initially, nodes on each layer network are coupled one-by-one as Fig. 1 illustrates. However, in real world networks, nodes' knowledge of shortest path is different from each other. To model this fact, we let the nodes on different layer networks coupled random. That is, we choose a portion of nodes on both layer networks and then change their coupled nodes on the other layer network. For example, in Fig. 1, the coupled node on the physical layer network of logical node F^{λ} is changed from $F^{\emptyset}$ to $G^{\emptyset}$, and $F^{\emptyset}$ is the new physical network coupled node of H^{λ} replacing node $H^{\emptyset}$. In this case, each logical edge corresponds to a shortest path on the physical network. For instance, the edge $e(F^{\lambda}, G^{\lambda})$ on the logical network corresponds to the shortest path $G^{\emptyset}$–$H^{\emptyset}$–$I^{\emptyset}$ on the physical network. A physical path corresponding to a logical path is the joint of each logical edge's physical path. For example, $B^{\emptyset}$–$F^{\emptyset}$–$G^{\emptyset}$–$H^{\emptyset}$–$I^{\emptyset}$ is the physical path corresponding to its logical path B^{λ}–F^{λ}–G^{λ}.

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