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Enhancing traffic capacity of scale-free networks by employing hybrid routing strategy

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HIGHLIGHTS

- Hybrid routing strategy includes the shortest path and global dynamic routing.
- Packets are sent along the shortest paths or with dynamic source routing information.
- The global dynamic source routing strategy is employed as a supplementary routing.
- The traffic capacity is remarkably enhanced with a little average path lengthening.

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ABSTRACT

Based on the consideration of easy implementation of new routing strategies on many real complex networks such as the Internet, we propose a hybrid routing mechanism composed of the shortest path routing and the global dynamic routing strategy to improve the network traffic capacity. Under the background of current routing policy and network structure, packets can be sent along the shortest paths or by using source routing information. In this work, a global dynamic source routing strategy is employed as a supplementary routing mechanism to bypass central nodes and increase the delivery capacity utilization of all nodes significantly in the network. The traffic capacity of networked complex systems can be enhanced tens of times at the cost of a little average path lengthening. This hybrid routing method is very useful to network service providers and can be constitutionally supported on several networked complex systems such as the Internet and wireless ad hoc networks.

1. Introduction

Various complex networks give us abundant conveniences every day: social networks composed of individuals interacting through social connections facilitate the acquaintances of new friends around us; the Internet where vertices are routers and edges are links to other routers provides us basic infrastructure for information sharing, etc. The structure of these complex networks has been found Small-World (SW) [1] phenomenon and Scale-Free (SF) [2,3] properties, and the shortest path routing (SP) strategy is often used for determining the routes between any two nodes. With the immense increase of traffic amounts in many networked communication networks or transportation networks, congestion occurs continually and brings negative effects on the quality of our daily life. One driver cannot bear extremely long travel time from working place to his home in rush hours by choosing the shortest path which is also the favorite choice of most other people.

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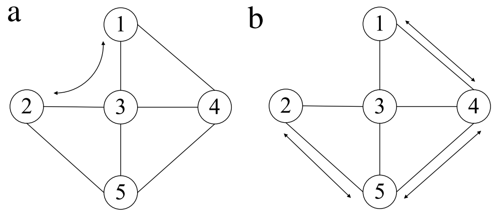

Fig. 1. (Color online) A simple network structure. (a) Paths determined by the shortest path routing strategy; (b) Paths determined by the global dynamic routing strategy.

Recently, number of researchers are studying the traffic dynamics on complex systems to find out efficient approaches to control or avoid traffic congestion. Methods for improving traffic capacity of complex systems are mainly divided into three categories: optimizing the routing strategy [4–33], changing network structure [34–40], and allocating limited network resources available such as link's bandwidth [41–43], node's delivering capacity [44–49] and so on.

Under the shortest path routing, packets traversing from their sources to destinations easily choose central nodes of network to pass through. Due to the limited delivering capacity of each node, the massive packets cannot be delivered on time and accumulate heavily on central nodes, and subsequently traffic congestion occurs. As showed in Fig. 1(a), node 3 is the central node which is easily congested under the SP routing policy. For instance, the path between nodes 1 and 2 is $P_{1,2} = \{1, 3, 2\}$. As we know, with proper optimization of routes for a fraction of node pairs, the traffic jams can be significantly reduced. For example, if the path between nodes 1 and 2 is planned as $P_{1,2} = \{1, 4, 5, 2\}$ in Fig. 1(b), traffic load on central node 3 will decrease.

This paper is organized as follows. In Section 2, the network model and traffic model is described. In Section 3, a hybrid routing mechanism is introduced, and extensive simulations will be done to support the effectiveness of the hybrid routing. Finally, the paper closes with conclusions in Section 4.

2. Network model and traffic model

2.1. Network model

Due to the heterogeneous structure of many real complex networks such as the Internet, there are many drawbacks on using the shortest path routing: (1) low traffic capacity; (2) a large portion of nodes with low delivery capacity utilization. To illustrate it clearly, we first do simulations on Barabási–Albert (BA) [2,3] scale-free networks with network size $N = 400$, average degree $\langle k \rangle = 8$. The BA scale-free network is constructed as follows.

Starting from m_0 fully connected nodes, a new node with m ($m \leq m_0$) edges is added to the existing network, and the other end of each new edge is chosen preferentially according to the probability

$$\Pi_i = \frac{k_i}{\sum_j k_j}, \tag{1}$$

where k_i and k_j are the degrees of node i and node j respectively. Without loss of generality, here we set $m = 4$, and $m_0 = 9$.

2.2. Traffic model

Network model is the basic infrastructure for dynamic traffic taking place on. Traffic model reveals the dynamic running progress of traffic on the network model. We regard each node as both host and router which can either generate packets or forward packets. Each node can deliver at most C (here, we set $C = 1$) packets to its immediate neighbors. At each time step, there are R packets generated in the network with randomly chosen sources and destinations. The First-In–First-Out (FIFO) discipline is used at each queue. Once a packet arrives at its destination, it is removed from the system immediately. If there are several paths between two nodes with equal minimum cost, one of them is chosen randomly.

The network traffic capacity can be measured by the maximal packet generation rate R_c, at which the phase transition from free to congested flow takes place. It can be denoted by the order parameter [50]

$$H(R) = \lim_{t\to\infty} \frac{C}{R} \frac{\langle \Delta W \rangle}{\Delta t}, \tag{2}$$

where $\langle \Delta W \rangle = W(t + \Delta t) - W(t)$ and $\langle \ldots \rangle$ denotes the average over time windows of width Δt. $W(t)$ is denoted as the number of packets in the network at time t. When $H = 0$, the numbers of new generated packets and removed ones are balanced, and no congestion occurs. When the packet generation rate R is large enough, more and more packets cannot be delivered timely and accumulate on many central nodes over time, finally resulting in traffic congestion.