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An efficient probability routing algorithm for scale-free networks

Wei yan Liu[a,*], Xin Li[b], Jun Li[c], Bin Liu[a]

[a] Department of Information Engineering, Jiangsu Open University, Nanjing 210017, Jiangsu Province, China
[b] College of Engineering and Applied Science, University of Wisconsin-Milwaukee, Milwaukee WI 53211, USA
[c] Department of Telecommunication Engineering, Zhejiang Wanli University, Ningbo 315100, Zhejiang Province, China

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ABSTRACT

To better utilize hub nodes within a network, this paper proposed an efficient probability (EP) routing algorithm which features using the importance degree to target critical nodes and subsequently redistribute incoming packets. Simulation results reveal that the proposed strategy is able to improve the network capacity in comparison to the shortest path (SP) routing strategy and the centrality-degree-based probability path (PP) routing algorithm. Moreover, the average routing path length of the EP is over 30% shorter than that of the PP, though it is 10% longer than that of the SP.

1. Introduction

Significant discoveries of the small-world effect [1] and scale-free characteristics [2] have triggered a great deal of research interest in the study of complex networks. In particular, a substantial focus has been on their structure and dynamics [3,4]. A scale-free network is a network whose degree distribution follows a power-law. Many networks have been reported to be scale-free [5–7], such as computer networks [8,9], urban transport or highway networks [10], and social networks [11,12]. With the development of large networks, the call for high efficiency in the handing and delivering of information increases, thus it is of great interest to study the traffic flow on scale-free networks.

The aim of building a computer network is to deliver data, where the network infrastructure and routing strategies [13–16] play an important role in effective data transmission. In normal practice, it is far more difficult and costly to change or reconstruct the underlying network infrastructure when contending with a variety of network applications [17]; effective routing strategies are thus usually implemented as an easy and practical approach to improve network performance. Thus, the study of network routing protocols naturally has turned into an active research area [18–20]. A series of corresponding algorithms have been proposed for enhancing the capacity of network traffic. Traditionally, network routing is based on the best available approximation to the shortest paths (SP) between any two nodes of the network, and then the routers forward the data packets along the selected paths. However, this strategy may not work well with a scale-free network, due to the central nodes with high-degree or high-betweenness [21,22] that will easily attract a great number of packets and subsequently tend to be congested. To mitigate this issue, some enhanced routing strategies based on scale free networks were further developed. Huang et al. investigated the combined effect of the local and global topological ingredients of the

* Corresponding author.
E-mail address: sdnjlwy1973@163.com (W.y. Liu).

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routing packets on the transport efficiency under different degree exponents, and further proposed an improved routing algorithm based on memory information [23]. Jiang et al. proposed a heuristic routing strategy to improve the traffic capacity of complex networks, which computes all paths for one source node by considering dynamic betweenness, centrality and degree information [24]. Zhao et al. proposed an adaptive routing strategy, where the probability of a node to transmit packets to its neighbors is adjusted by the relationship between the neighbors' traffic load and the sending capacity [25]. In addition, many other researchers concentrated on developing dynamic routing strategies. Naganuma proposed a dynamic packet routing strategy in which the path length to the packets' destinations was adopted as a benchmark for adjusting the connection weights of the networks [26].

In a scale-free network, the central nodes are more susceptible to traffic congestion because of the rapid traffic aggregation which then spreads to all other nodes, and some critical nodes are ignored. Therefore, by locating the critical nodes and redistributing the traffic load we are able to prevent the central nodes from traffic congestion. The degree [27], betweenness and closeness centralities [28–30] have been applied to rank node importance. Among these, the degree of centrality is relatively simple and efficient, but it neglects the global structure of the network, which may result in the fact that some critical nodes such as bridge-nodes are missed. Although betweenness and closeness centrality are capable of improving such issues, they are incapable of being applied to large complex networks due to the high computational complexity. To solve the above-mentioned problems, we proposed an efficient probability (EP) routing strategy which features using the importance degree to target critical nodes and redistribute incoming packets. It has the benefits of: 1) minimizing the side effects of congestion at an earlier stage by means of distributing the traffic loads evenly, 2) preventing the central nodes from being bottlenecks, and 3) utilizing the critical nodes more efficiently.

The rest of the paper is organized as follows. Section 2 introduces the network models. Section 3 describes node importance and the efficient probability routing strategies in detail. Simulation results and discussions are presented in Section 4. Section 5 concludes the paper.

2. The network models

Scale-free networks are widely observed in natural and human-made systems, including citation and co-author scientific networks, the internet and world-wide web, gene regulatory networks, and some social networks [6]. These networks typically follow power-law degree distributions. The Barabási-Albert model (BA) is one of the proposed models that can generate scale-free networks [2]. The network begins with an initial connected network consisting of m_0 nodes, and new nodes are supplemented into the network each time. Every new node is linked to existing nodes with a probability that is proportional to the number of links containing existing nodes. The degree of a node is the number of edges connected to the node. The new nodes have a preference to attach themselves to the central nodes. The BA model is given as follows:

(1) Growth:

Step 1: Initially, at the beginning there are n_0 isolated nodes, at each time step;
Step 2: A new node is added to the network proposed in Step 1 and connected to n ($n \le n_0$) different nodes within the network.

(2) Preferential attachment:

The probability of an existing node connecting with a new node is proportional to the amount of links connected with the other nodes.
The probability of a new node connecting to node i depends on the degree k_i of node i, which is mathematically described by Eq. 1:

$$P(k_i) = k_i / \sum_{j=1} k_j \tag{1}$$

Both growth and preferential attachment exist widely in real networks.
To ensure that the proposed model fits well with the real-world situations, this study considers the following definitions:

- All of the nodes as both hosts and routers;
- At each time step, λ packets will be generated;
- Node i can deliver c packets per time step towards their destinations;
- The queue length of each node is infinite;
- Packets are delivered based on the principle of the first-in-first-out strategy, once packets arrive at their destinations, they will be removed from the system. Otherwise, the packets will be delivered to neighboring nodes according to the probability $p(k_i)$.

3. An efficient probability routing strategy

The proposed routing strategy for each path between nodes i and j is defined as [22] Eq. 2:

$$P[i \to j] \equiv (i \to x_0 \to \cdots \to x_n \cdots \to j) \tag{2}$$