Physica A 392 (2013) 953–958

Contents lists available at SciVerse ScienceDirect

Physica A

journal homepage: www.elsevier.com/locate/physa

Probability routing strategy for scale-free networks

Xiaojun Zhang [a,*], Zishu He [b], Zheng He [c], Lez Rayman-Bacchus [d]

[a] School of Mathematical Sciences, University of Electronic Science and Technology of China, Chengdu, 611731, PR China
[b] School of Electronic Engineering, University of Electronic Science and Technology of China, Chengdu, 611731, PR China
[c] School of Management and Economics, University of Electronic Science and Technology of China, Chengdu, 611731, PR China
[d] London Metropolitan University, London, N7 8HN, UK

ARTICLE INFO

Article history:
Received 30 March 2012
Received in revised form 30 June 2012
Available online 17 October 2012

Keywords:
Probability routing strategy
Scale-free networks
Network capacity
Average routing path length

ABSTRACT

This study proposes a probability routing strategy for improving traffic capability on scale-free networks. Compared with the shortest path routing strategy depending on central nodes largely and the efficient routing strategy avoiding hub routers as much as possible, the probability routing strategy makes use of hub routers more efficiently, transferring approximate average amount of packs of the whole network. Simulation results indicate that the probability routing strategy has the highest network capacity among the three routing strategies. This strategy provides network capacity that can be more than 30 times higher than that of the shortest path routing strategy and over 50% higher than that of the efficient routing strategy. In addition, the average routing path length of our proposed strategy is over 10% shorter than that of the efficient routing strategy and only about 10% longer than that of the shortest path routing strategy.

1. Introduction

Recently, issues related to improving network capacity for various complex networks, such as packet transfer on the Internet, information delivery in communications networks, and goods transportation on complex road networks, have received tremendous attention from the research community. Most existing studies have been focused on the phase-transition phenomena [1–4], the scaling of traffic fluctuations [5–8], the routing strategies of network traffic [9–26], and the effects of network topology on routing [11,27,28]. Compared with expensive infrastructure modifications, optimized routing strategies have been proven to be more efficient in enhancing network capacity. Past studies have shown that on scale-free networks the traditional shortest path routing strategy often leads to network congestion as large numbers of packets are transferred through hub routers with high degree and betweenness [9–15,19]. To address this deficiency, many alternative strategies have been proposed to avoid hub routers. For example, global dynamic routing strategy [10–12] considers the number of packets on each router to be an important factor in determining the shortest path; edge deletion approach [13] improves transmission efficiency through removing the edges of linking to nodes with large betweenness; link-closing strategy [14] enhances traffic capacity by closing or cutting some links between some large-degree nodes and optimal transport algorithm [15] suggests that a network capacity is determined by the maximum value of node betweenness. Therefore, from a theoretic viewpoint, a network can sustain significantly higher traffic capability by minimizing the maximum node betweenness. In particular, the efficient routing strategy by Yan et al. [9], weighs each edge with the sum of two connecting nodes' degrees to find the shortest weighted path as the routing path. Simulation shows that the efficient path is able to avoid hub routers effectively and reach a very high capacity of more than ten times that of the shortest

---

[*] Corresponding author.
E-mail address: sczhxj@gmail.com (X. Zhang).

0378-4371/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
doi:10.1016/j.physa.2012.10.012

path routing strategy. However, the efficient routing strategy does not utilize hub routers efficiently, since their hub routers support very little of the packet transmission tasks. Therefore, there lies the opportunity for alternative routing strategies to increase network capacity and shorten routing path distance by utilizing hub routers more efficiently.

This study proposes a probability routing strategy for scale-free networks with degree distribution exponent $\gamma = 3$ [29]. In contrast to the shortest path routing strategy depending on hub routers largely and the efficient routing strategy avoiding hub routers as much as possible, the probability routing strategy makes use of hub routers more efficiently, providing a balanced approach of the two aforementioned strategies by considering the roles of hubs and other nodes simultaneously. Simulation results indicate that compared with the shortest path routing strategy and the efficient routing strategy, the probability routing strategy provides the highest network capacity. In some cases, the probability routing strategy can generate a network capacity over 30 times higher than that of the shortest path routing strategy and more than 50% higher than that of the efficient routing strategy. In addition, the average routing path length of our proposed strategy is over 10% shorter than that of the efficient routing strategy and only about 10% longer than that of the shortest path routing strategy.

This paper is organized as follows. Section 2 introduces the probability routing strategy. Different parameters are tested in order to identify the optimal value. In Section 3, simulation results are presented to compare the efficacy of three routing paths (the probability path (PP), the efficient path (EP) and the shortest path (SP)) in terms of critical measurements such as network capacity and average routing path length on various scale-free networks. Finally, Section 4 discusses the conclusion of the study and provides suggestions for future research.

2. The probability routing strategy

For consistency, this study makes the same assumptions as other literature [9,10,15,21]:

1. all nodes are a mix of hosts and routers which have the same capabilities of delivering and handling information packets;
2. each node creates one packet at the rate η and transfers to another node with a fixed routing table;
3. one node can only handle one packet at each time unit using the "First-In–First-Out" rule, and once a packet arrives at its destination, it is removed from the network.

Under these assumptions, it is obvious that the lower the packet generation rate η, the faster the packet reaches its destination, due to less congestion and shorter waiting time on the network. As η increases, more and more packets accumulate on various nodes and packets' waiting time increases, which ultimately leads to a complete halt of network traffic. During this process, there exists a critical value η_c. In the case of $\eta < \eta_c$, the network operates smoothly with a steady traffic flow, whereas if $\eta > \eta_c$, a phase transition occurs from free flow to congested traffic. Thus η_c can be used as a measure of network capacity. In general, a good routing strategy generates a high network capacity η_c as well as short average routing path length L [9]

$$L = \frac{\sum_{u=1}^{N}\sum_{v=1}^{N} L_{u,v}}{N * (N-1)} \tag{1}$$

where $L_{u,v}$ denotes the routing path length from node u to v, i.e. the number of passing nodes for a packet from node u to v.

In order to utilize hub routers more efficiently, there needs to be a new routing strategy to reduce the waiting probability of a package on the routing path. Here the probability of a packet non-waiting on a node should be negatively related to the degree of this node. Accordingly, a new routing function is proposed

$$R\left(\alpha, P\left(i \to j\right)\right) = \prod_{u \in P(i \to j)} \left[\frac{1}{\ln\left(1 + k_u\right)}\right]^{\ln(1+\alpha \cdot k_u)} \tag{2}$$

where $P\left(i \to j\right)$ represents a path from source i to destination j, $u \in P\left(i \to j\right)$ denotes the node u on the path $P\left(i \to j\right)$, k_u is the degree of node u, and $\left[\frac{1}{\ln(1+k)}\right]^{\ln(1+\alpha \cdot k)}$ is a probability function with a parameter α ($\alpha > 0$). The path which yields the maximum value for the routing function $R\left(\alpha, P\left(i \to j\right)\right)$ is the probability routing path $P^*\left(i \to j\right)$

$$R\left(\alpha, P^*\left(i \to j\right)\right) = \max_{P(i \to j)} \left\{R\left(\alpha, P\left(i \to j\right)\right)\right\} = \max_{P(i \to j)} \left\{\prod_{u \in P(i \to j)} \left[\frac{1}{\ln\left(1 + k_u\right)}\right]^{\ln(1+\alpha \cdot k_u)}\right\}. \tag{3}$$

On the one hand, because $\left[\frac{1}{\ln(1+k)}\right]^{\ln(1+\alpha \cdot k)}$ is a strictly monotone decreasing function with the degree $k \quad (k \geq 2)$, $R\left(\alpha, P^*\left(i \to j\right)\right)$ means a packet has a higher probability of avoiding the central nodes. On the other hand, since $\left[\frac{1}{\ln(1+k)}\right]^{\ln(1+\alpha \cdot k)} < 1$, $R\left(\alpha, P^*\left(i \to j\right)\right)$ implies that a packet from node i to j passes through fewer nodes, that is, the probability routing strategy provides shorter average routing path length.

In the probability routing path $P^*\left(i \to j\right)$, α is crucial to the network capacity. To find the optimal α, the relationships between critical value η_c and α for various BA networks have been tested. The tests indicate that the maximum η_c can be