Physica A 392 (2013) 2294–2301

Contents lists available at SciVerse ScienceDirect

Physica A

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

Efficient routing on small complex networks without buffers

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ARTICLE INFO

Article history:
Received 10 August 2012
Received in revised form 29 November 2012
Available online 17 January 2013

Keywords:
Scale-free networks
Routing
Network capacity

ABSTRACT

In this paper, we are exploring strategies for the reduction of the congestion in the complex networks. The nodes without buffers are considered, so, if the congestion occurs, the information packets will be dropped. The focus is on the efficient routing. The routing strategies are compared using two generic models, i.e., Barabàsi–Albert scale-free network and scale-free network on lattice, and the academic router networks of the Netherlands and France. We propose a dynamic deflection routing algorithm which automatically extends path of the packet before it arrives at congested node. The simulation results indicate that the dynamic routing strategy can further reduce the number of dropped packets in a combination with the efficient path routing proposed by Yan et al. [5].

1. Introduction

Complex networks are important for the functioning of the modern society. To ensure a free, uncongested traffic flow on the complex networks is of great interest. Intuitively, the traffic congestion could be largely reduced or completely avoided with a very large average degree of connectivity and/or node capacity for information packet delivery. The capacity of nodes to deliver information cannot be infinite. Also, upgrading the infrastructure is often not economically feasible [1,2]. The performance of the communication systems can be improved by implementing the more appropriate routing protocols without changing the underlying network structure [3–17], which is more realizable in the practice. Such work presents two problems. The first is finding out the optimal strategies for the traffic routing on a defined network structure. The second problem is finding a procedure to draw general conclusions about performance of routing strategies due to the variation of the real network topologies. The increasing speed of the network interfaces raises an important question concerning the size of buffers, complexity and cost. A considerable research effort is currently under way in an attempt to resolve compromise between buffer latency and complexity on one side and capacity on the other [18–25]. In the previous studies, the node buffer size in the traffic-flow model is set as infinite [3–16]. Our intention is to produce a relatively simple methodology for evaluating routing strategies in networks with limited buffering capability or without optical buffers. This should be important for the optical networks with either large volumes of the information traffic or without buffering capacity.

A number of network models are introduced in the past two decades [26,27]. A particular class of models is dedicated to networks embedded in the space [28]. Here we are interested in evaluating the models for representation of the spatially constrained networks, both in terms of distance between nodes and the extent of the network. We are interested in information flow optimization in small networks. Small networks should represent bulk of telecommunication networks or other dedicated information networks, e.g., regional optical backbones and academic networks. As examples of the real-world networks, we analyze the national research and educational networks (NRENs) of the Netherlands [29], France [30], Norway [31] and Spain [32] and compare them with Barabàsi–Albert scale-free network and scale-free network on lattice. The system size dependence of topological characteristics of the scale-free network on lattice is also analyzed.

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doi:10.1016/j.physa.2013.01.033

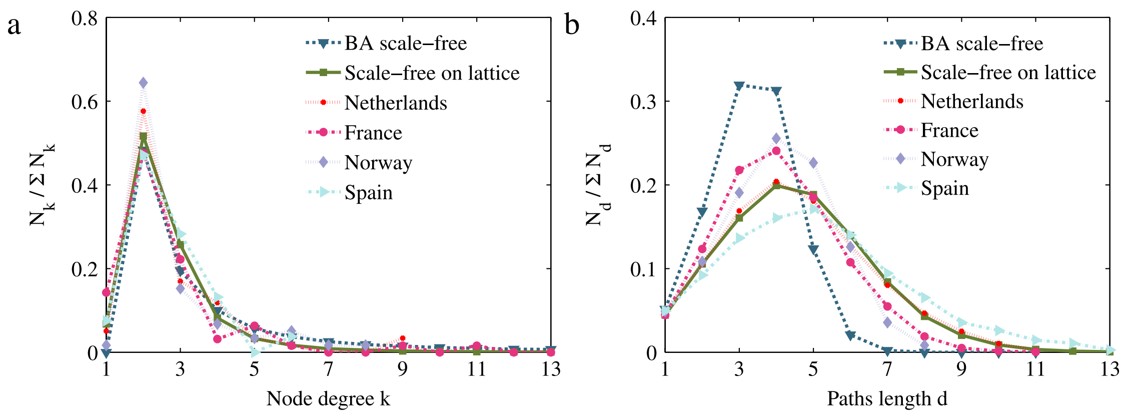

Fig. 1. Topological characteristics: (a) degree distribution; (b) length of path probability density function for NRENs of the Netherlands ($N = 59$), France ($N = 63$), Norway ($N = 58$) and Spain ($N = 53$) and generic network models: BA scale-free network ($N = 64$, $m = 2$) and scale-free network on lattice ($N = 64$, $\lambda = 2$).

In this work, three routing strategies are implemented and evaluated: the shortest path routing, efficient path routing and dynamic deflection routing. The shortest path routing is widely used routing strategy in praxis (by "shortest" we mean the path with the smallest number of links) [33]. However, in the shortest path routing strategy load distribution is not homogeneous. The majority of the shortest paths pass through the nodes that are highly connected, while other nodes carry much less traffic [34]. Yan et al. [5] presented an approach to redistribute traffic load in highly connected nodes to other nodes using link weight. An improvement is achieved through a targeted traffic redistribution from the most congested nodes. As result the congestion is reduced at the expense of a slight increase of the total path length and traffic. We compare this routing strategy with a dynamic routing strategy. The dynamic routing strategy improves the control of the congestion in the heavily loaded nodes by dynamically returning packet one step back. In this way, the dynamic strategy uses the redundant capacity of the links in network to temporarily store information, until congested node capacity is free. Further, we test a possibility of combining dynamic and static routing strategies. In order to check how different routing strategies behave in the larger networks, we have evaluated information loss dependence on packet generation rate and network size in case of the scale-free network on lattices.

The paper is organized as follows: in Section 2 we introduce the generic scale-free model and the scale-free model on lattice and compare their network characteristics with the national research and educational networks (NRENs) of the Netherlands, France, Norway and Spain. Furthermore, the characteristics of the scale-free model on lattice for different system sizes are considered. In Section 3, the information flow model and a measure of system performance are introduced. The static and dynamic routing strategies are described in Section 4 and their performance is analyzed in Section 5.

2. Network models

In this work, we compare topological network characteristics of Barabàsi–Albert scale-free model [26], the scale-free model on lattice [28] and the national research and educational networks (NRENs) of the Netherlands, France, Norway and Spain. Barabàsi and Albert observed an existence of a high degree of self-organization characterizing the large-scale properties of complex networks [26]. They have introduced a model of the scale-free networks with two key elements: probability that a new node connects to the existing nodes is not uniform and there is a higher probability that it will be linked to a node that already has a large number of connections. Thus, Barabàsi–Albert (BA) scale-free network model is formed in a series of steps in which new nodes are incorporated into the network. Algorithm is starting with a small number (N_0) of nodes, and at every time step new nodes with m connections are added. To incorporate preferential attachment, the model assumes that the probability of the new connection with the node i depends on its connectivity k_i and equals $P(k_i) = k_i / \sum k_j$. After a few algorithm steps, distribution of number of links per node takes scale-free form $P(k) \sim k^{-\lambda}$. In this work, for $N_0 = 3$ and $m = 2$, $n = 61$ algorithm steps are preformed. Obtained network consists of $N = 64$ nodes with $\lambda = 2$. The obtained network degree distribution corresponds well to the NRENs; cf. Fig. 1(a). The number of nodes in different NRENs is in the case of the Netherlands $N = 59$, France $N = 63$, Norway $N = 58$ and Spain $N = 53$.

However, the real-life networks are embedded into the geographical space and constrained by the cost of the links between the nodes. In the scale-free model on lattice (cf. [28]) the algorithm starts with a set of nodes that are identified with the set of lattice vertices in an $M \times M$ square. The lattice distance between two nodes is defined as the minimal number of "lattice steps" separating them in the regular lattice. In this model, network nodes are randomly assigned with the number of links (k) according to scale-free distribution $P(k) = Ak^{-\lambda}$, $m \leq k < K$ and connected to its closest neighbors. Therefore, exponent λ is a model parameter. We set $\lambda = 2$, as obtained from the connectivity distribution of NRENs; cf. Fig. 1(a). The choice of model parameter λ is also in accordance with the distribution of the number of links per node obtained with BA model. Normalization constant is $A \approx (\lambda - 1)m^{\lambda-1}$.