Commun Nonlinear Sci Numer Simulat 25 (2015) 136–144

Contents lists available at ScienceDirect

Commun Nonlinear Sci Numer Simulat

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

Competition and fitness in one-mode collaboration network ☆

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ARTICLE INFO

Article history:
Received 22 July 2014
Received in revised form 1 December 2014
Accepted 28 January 2015
Available online 7 February 2015

Keywords:
Collaboration network
Degree distribution
Fitness-driven preferential attachment
Mean-field approach
One-mode RDP model

ABSTRACT

The fitness to compete for links is a very critical factor to decide the rate that nodes increase their connectivity in a network. In this paper, the node degree distribution of one-mode collaboration model (one-mode RDP model) is researched by mean-field approach and we obtain the node degree distribution of this model is a power-law distribution for large enough node degree k. Some numerical simulations are made to verify the feasibility of the node degree distribution for this model. Then we improve the one-mode RDP model for the competitive evolving network and come up with a model that is one-mode RDP model based on fitness-driven preferential attachment (we call this model one-mode RDP model with fitness). We discover that the fitter nodes can acquire more connectivity and the dynamic exponent depends on the fitness η. By calculating the dynamic exponent $\alpha(\eta)$, a general expression for the node degree distribution of one-mode RDP network with fitness is acquired. Given the fitness distribution $\rho(\eta)$, the explicit form of the node degree distribution can also be obtained. The analytical predictions are found to be in good agreement with the experimental results derived by numerical simulations.

1. Introduction

Complex networks in which the nodes stand for the units consisting of the network, and the edges represent the interrelation between pairs of units can describe plenty of real complex systems, such as social network [22], World Wide Web [2], biological interacting networks [18]. Complex network research upsurge first stems from Watts–Strogatz 'small-world' network model [23] and Barabási–Albert model (BA model) [3,4]. For a long time, these models have been regarded as completely random [3,4,23], but in real-world networks, there are many phenomena are not completely random [2,8,11]. BA model displays that the probability $\prod$ that a new node chooses to connect an 'old' node i (that have existed in the network) is $\prod(k_i) = \frac{k_i}{\sum_j k_j}$ called preferential attachment mechanism, so the older nodes have higher degree. But BA model neglects such a question that not all nodes are equally successful in competing for links in real networks [1]. This question indicates that classical random networks [6,10] can not stand for real-world networks very correctly [2,8,11].

There are many examples that can demonstrate that in real-world networks the connectivity among nodes is not completely random and the connectivity and growth rate of nodes does not also only rely on their age. For instance, some new webpages with good and popular content can obtain more connectivity than some older webpages on the internet. In the science citation network, some new research papers containing high academic level content can be cited by numerous

☆ Supported by National Natural Science Foundation of China (71471106), and Special Research Fund for the Doctoral Program of Higher Education (20133704110003).

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http://dx.doi.org/10.1016/j.cnsns.2015.01.019
1007-5704/

research papers in a short time. These facts indicate that nodes have different ability to compete for links. In [12], Bianconi and Barabási develop the BA model and propose a model that can help us to study this competitive aspect of real networks. They use the node's fitness to describe the node's ability to compete for links, such as the content of a webpage, or the content of a research paper. They add the node's fitness into the preferential attachment and find the rate at which nodes increase their connectivity also depends on the fitness of the node. In [16], Lee, Chan and Hui improve the model in [12] and propose a model that shows a hybrid of the growing networks based on popularity-driven and fitness-driven preferential attachment. In the evolving process of this network, a new node with m new links is added into the network and connects to m 'old' nodes with a probability p based on popularity of the 'old' nodes and a probability $1-p$ based on fitness of the 'old' nodes. The two papers both acquire the general expression for the connectivity distribution.

Collaboration network [7,9,17,19,21] is an important social network [22]. It is generally represented as a bipartite graph that contains 'participant' and 'project' denoted by two disjoint node sets. If participants work on a common project together, they connect to each other. There are many real application examples of collaboration network, such as scientific collaboration network [19], trade network [13], music network [15,20]. In [21], a more influential collaboration network that is the self-organization evolving bipartite graph model (RDP model) is proposed. In the RDP model, a new project with n participants is added at each time step. Among the n participants, m participants are 'new' participants who do not have previous experience, and the rest $n-m$ participants are chosen from the 'old' participants that have existed in the network with a probability proportional to the number k of projects that they previously participant in. Using master equation method, Ramasco et al. [21] find that the participant nodes' degree distribution of RDP model approximately manifests a power-law distribution. Although collaboration network is represented as a bipartite graph, the one-mode projections of these bipartite graphs are empirically studied. In these projections, the project nodes are excluded, and participants that collaborate in a common project are connected by edges. In [24], Wang and Ma translate two-mode collaboration network model (RDP) into one-mode RDP model. By rate-equation approach, they gain the conclusion that for large enough node degree k, the participant nodes' degree distribution of one-mode RDP model is approximately a power-law distribution. In our paper, we also obtain the similar conclusion by mean-field approach.

We find that there are few articles considering the competitive aspect of collaboration network [5,14]. So we propose a model that is one-mode RDP model based on fitness-driven preferential attachment (we call this model one-mode RDP model with fitness). In this model, we also employ the fitness to denote the node's ability to compete for links. We add the fitness to the preferential attachment mechanism of one-model collaboration network [24], that is, $\prod(k_i) = \frac{\eta_i k_i}{\sum_j \eta_j k_j}$, called fitness-driven preferential attachment mechanism [12,16]. We find $\prod_i$ depends on the connectivity k_i and the fitness η_i. That indicates in one-mode RDP model with fitness, the node who is young but has higher fitness (or has stronger ability to compete for links) can also have higher number of links. So one-mode RDP model with fitness can help us to better understand the competitive aspect of collaboration network.

The main motivation of our study contains two aspects. First, in [21,24], they do not consider the competitive aspect of collaboration network. Second, in [12,16], although they consider the competitive aspect of the network, their models are that at each time step, only one new node with l edges (that will be connected to l nodes already present in the system) is added; however, in our paper, we consider the one-mode RDP model with fitness is that at each time step, m new nodes are added, where $m \geqslant 1$ and they connect with each other, and each new node connects to $n-m$ 'old' nodes that already exist in the network. In real world, there are generally more than one new participants join in a new collaboration project. In our model, the number of new participant nodes is m and $m \geqslant 1$. Based on the above points, we find that one-mode RDP model with fitness is closer to the actual situation and can better reflect "Competition exists in cooperation" in real world. The model can more widely be used in real life, such as scientific collaboration network and trade network, so it is very meaningful and important for real world.

When $m = 1$, our model reduces to the model in [12] and the model of [16] with $p = 0$. In [12,16], they acquire a general expression for the node degree distribution and given the fitness distribution $\rho(\eta)$, the explicit form of node degree distribution is derived. In our paper, when $m = 1$, we also obtain the same explicit form of node degree distribution in [12,16] with $p = 0$. Then we extend the conclusion and consider the more general situation. The main contribution of this paper is that when $m \geqslant 1$, we acquire the general expression for the node degree distribution, and when the fitness distribution functions are given by $\rho(\eta) = \delta(\eta - 1)$, when $m = 1$ and $\rho(\eta) = 1, \eta \in [0, 1]$, when $m \geqslant 1$, we also derive the explicit forms of node degree distribution.

In this paper, we mainly analyze the node degree distribution of one-mode RDP model based on fitness-driven preferential attachment. For calculating the node degree distribution of one-mode RDP model with fitness, we firstly need to consider the node degree distribution of one-mode RDP model by mean-field approach. We organize this study as follows. In Section 2, the one-mode RDP model is given. By mean-field approach [4], we derive the node degree distribution of this model is a power-law distribution for large enough node degree k. And we make some numerical simulations to proof the conclusion. In Section 3, we propose the one-mode RDP model with fitness. We find that the dynamic exponent depends on the fitness η. By calculating the dynamic exponent $\alpha(\eta)$, we acquire a general expression for the node degree distribution through continuum theory and some theoretical results gained in Section 2. In Section 4, we give two fitness distribution functions that are $\rho(\eta) = \delta(\eta - 1)$ i.e. all fitness are equal and $\rho(\eta) = 1, \eta \in [0, 1]$ i.e. $\rho(\eta)$ is chosen uniformly from the interval [0, 1]. By the given fitness distributions, the explicit forms of node degree distribution are obtained. We find that the analytical predictions are in good agreement with the results derived from numerical simulations. Finally, we give the conclusion.