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Implantation of the global dynamic routing scheme in scale-free networks under the shortest path strategy

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ABSTRACT

The shortest path is a basic routing model which is still used in many systems. However, due to the low exploitation of the delivery capacity of peripheral nodes, the performance achieved by this policy is very limited. Starting from the fact that changing all network routers by others more robust is not practical, we propose the improvement of the capacity of a scale-free network under the shortest path strategy by the implantation of global dynamic routers. We have studied two targeting approaches to designate specific nodes to route the packets following the global dynamic protocol; one is based on node degree and the other on its betweenness. We show that we already exceed twice the capacity under the shortest path protocol with only 4% of global dynamic routers when we target nodes with high betweenness and 10% when we target nodes with high degrees. Moreover, the average travelling time remains low while the network capacity increases.

1. Introduction

In the last few years, network science has acquired much interest from physical and engineering communities [1–3]. In fact, complex networks are involved in various fields and disciplines, such as data mining and analysis [4–6], biological networks [7–9], transport networks, communication networks, to name but a few [10–14]. As most of real world networks, communication networks manifest a scale-free propriety [15–17]. Indeed, the analyses of Internet data performed during the mid-1990s contradict the prevailing assumption that Internet is a random graph [18].

To keep up with the increasing demand for these networks, it is necessary to enhance their performance. Studies have confirmed that the mitigation of traffic congestion could be accomplished either by improving networks topology or implementing efficient routing algorithms [19–22]. Regarding the first solution, several works have been proposed, such as allocating limited available link's bandwidth [23] and applying the link-closing strategy [24]. However, due to the expensive cost of changing the infrastructure, researches have focused on the second solution rather than the former one. The random walk has been studied extensively [14,25–27]. The shortest path routing algorithm proposed by Dijkstra [28] represents the fundamental model on which several works have been based [29–31]. The efficient routing strategy was also one of the successful models that exploit the static information of the lattice. In this model, the path between any source i and destination j is the one in which the sum of node degrees is a minimum [32].

In addition to the topological information, the traffic flow can be considerably improved using the dynamic properties of the network. In this regard, a number of routing strategies have been suggested. The traffic awareness protocol uses a parameter that defines the degree of dependency on structural and dynamic information [33,34]. Ref. [35] suggests to take into consideration the waiting time along probable paths. The optimal traffic awareness proposes a refined form of traffic awareness by adding a supplementary parameter that controls the contribution of the queue length in the routing process [36]. Still with regard to traffic awareness routing, in Ref. [37], the authors investigate the impact of using this approach on scale-free networks with different clustering. Based on local information, a routing strategy with preferential delivering exponent α has been introduced [38–40]. In Ref. [41], the authors defined the optimal routing strategy, based on the minimum information path for traffic delivery. In the global dynamic routing method [42], the path between nodes i and j $P(i \to j) := i \equiv x_0, x_1, \ldots, x_{l-1}, x_l \equiv j$, is denoted as:

$$P(i \to j) = min \sum_{v=0}^{l} [1 + q(x_v)] \tag{1}$$

Where $q(x_v)$ is the queue length of the node x_v and l is the path length. Fig. 1(a) shows a concrete example; In this case $l = 5$, thus

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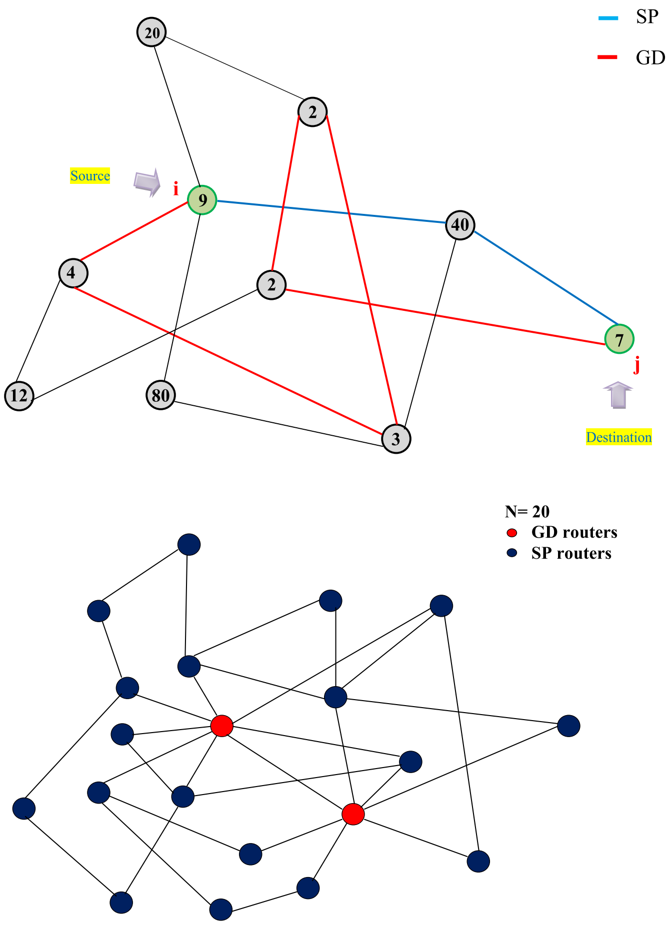

Fig. 1. (a) The shortest path and the global dynamic corresponding path between the nodes i and j; The numbers represent the queue lengths. (b) A hybrid routing network with the size $N = 20$, 90% of SP routers and 10% of GD routers.

$P(i \rightarrow j) = 33$. Comparing to the shortest path, the packet follows a long path between the source i and the destination j. However, it spends less time in the network. To deal with the high computational requirement caused by the variation of the queue lengths at each time step, the authors introduced a time delay δT to update the routing table. It has been shown that the network capacity remains the same despite the delay of the path update, at the cost of increasing the average travelling time. This routing strategy performed better than other previous routing schemes. Compared to the shortest path and the efficient path, the global dynamic balances the traffic load between hubs and peripheral nodes.

In general dynamic routings are suitable for very large networks. In fact, under these routing policies, networks are resilient against component failure (link or node). Indeed, they automatically find the appropriate alternative path for packets, taking into account the new topology of the network. Besides, the traffic load is properly distributed between network resources, which prevents rapid congestion. However, in addition to the high implementation and maintenance costs, the update of the routing table requires that routers share dynamic routing information, which puts additional load on router CPU, memory and bandwidth usage. Moreover, dynamic routings are less secure than static routings [43,44].

Using hybrid routing protocols is another interesting way to alleviate traffic jam in complex networks. Within this context, many approaches have been suggested [45–48]. Combining the shortest path and the global dynamic routing strategies has been already considered in Ref. [49]. It allowed a great amelioration of the network performance. However, this hybrid model requires that all nodes are equipped with global dynamic and the shortest path routers at once, since the packet nature that determinates how it will be routed. To mitigate the dynamic routing disadvantages introduced earlier, also since the shortest path is widely used in many fields [21,50,51], we decide to study the enhancement achieved when we implant global dynamic routers on a scale-free network under the shortest path protocol. The paper is organized as follows: In section 2, we introduce our hybrid routing method and we explain the selection criteria of the nodes that we substitute. In section 3 we discuss the simulation results then we summarize in section 4.

2. The model

In order to determine the routers that we should exchange, we test in independent simulations three selection procedures: Firstly, we place global dynamic routers on nodes chosen randomly among all network routers. Secondly, we target nodes with high degrees and lastly we target nodes with high betweenness. From now on, we use the acronyms SP and GD to designate the shortest path and the global dynamic models respectively.

For each case we use the well known Barabási–Albert model [52,53] to generate a scale-free network. In this model we start with m_0 full connected nodes then at each time step a new node is added and established m new links with the existing nodes according to the preferential attachment process. In our case the network size $N = 500$, $m_0 = 3$ and $m = 2$.

At first, all packets are forwarded following the SP then we gradually change a proportion of network routers with GD routers. The choice of exchanged routers is based on one of the procedures outlined above.

For example, Fig. 1(b) is an illustration of the hybrid model at 10% of GD routers. In this case GD routers are placed on high degree nodes. For each percentage of GD routers in the network and during the simulation time we repeat the following steps: R packets are created with random sources and destinations. Depending on the type of the router, each node delivers one packet to its neighbouring nodes according to the SP or the GD protocol. The packet is removed from the system once it reaches its destination. We assume that the queue lengths are unlimited and the First-In-First-Out (FiFO) policy is adopted.

For simplicity reasons, we set the time delay at $\delta T = 30$. To ensure the accuracy, we perform at least 20 independent runs with the same parameters for each selection pattern. Data are averaged and represented in the next section.

3. Simulation results and discussion

To pursue the phase transition of the traffic flow, we use the order parameter introduced by Arenas et al. [54,55]:

$$\eta = \lim_{t \to \infty} \frac{< Q(t+\tau) - Q(t) >}{\tau R} \tag{2}$$

Where τ is the observation time and $Q(t)$ is the total number of packets in the network at time t. In the free flow, the inflow and the outflow are in balance. With increasing number of packets there will be a specific packet generation rate R_c at which begins the transition to the congestion phase. $\eta = 0$ characterizes the free flow state ($R \leq R_c$), and $\eta > 0$ indicates the phase of congestion ($R > R_c$). Fig. 2 displays the order parameter as a function of the packets generation rate for different percentages of global dynamic routers. When the selection of nodes is done arbitrarily, the improvement of the capacity of the network is not as effective as when we target specific nodes. In fact when the percentage of GD routers is less than 30%, the betterment is barely observed, while in the targeted cases, we reach more than the double of the capacity under the SP protocol with only 4% of global dynamic routers