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Physica A

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Check-in based routing strategy in scale-free networks

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HIGHLIGHTS

- This work proposes a check-in based routing problem which is challenging and still open in many real artificial complex networks.
- A general check-in based routing mechanism is discussed to achieve basic packet navigation.
- By employing the efficient routing into check-in based routing, the network traffic capacity can be significantly enhanced.

ARTICLE INFO

Article history:
Received 31 May 2016
Received in revised form 3 October 2016
Available online xxxx

Keywords:
Check-in based routing
Traffic capacity
Efficient routing
Betweenness
Scale-free network

ABSTRACT

In many real complex artificial networks, a navigation route between a pair of source and destination is often desired to pass through at least a specified node called check-in node for doing check-in like services, such as gas fuel supplement for vehicles, GPS recording for express packages and so on. However, currently, there is a lack of routing study for complex networks equipped with check-in nodes. In this work, we first propose a general routing mechanism called check-in based routing (CBR) which can guarantee that every efficient path must include at least one check-in node. With a finite fraction of check-in nodes in the network, it can be observed that the higher the degrees of check-in nodes, the higher the network traffic capacity will be by employing the shortest path routing into CBR (namely CBR-SP). It is a great challenge on routing optimization for a network with a fraction of check-in nodes of the lowest degrees. We then employ the degree-based efficient routing (ER) into the CBR to efficiently redistribute heavy traffic from hub nodes to non-hub nodes. Under the CBR-ER, the traffic capacity can be significantly enhanced at the cost of a little network diameter and average path lengthening. The extensive simulations in scale-free networks can well confirm the effectiveness of CBR-ER.

1. Introduction

Networked complex systems are ubiquitous around the world. The Internet is fundamental infrastructure for transferring information packets which are the basic objects of various and useful network applications such as the World Wide Web (WWW), Email, instant communication software, online shopping, and online social activities. The road networks of modern cities and highway networks are the basic infrastructures of massive vehicles. Many other artificial networks such as power grids, airline networks, and so on also play very important roles in our daily lives. There is a common demand which is the navigation or routing in these artificial systems. Without routing, packets in the Internet have no fast routes to arrive at their destinations, and drivers in road networks might not be able to discover efficient paths quickly. Heavy traffic congestion may

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http://dx.doi.org/10.1016/j.physa.2016.11.011
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Please cite this article in press as: Z.-Y. Jiang, et al., Check-in based routing strategy in scale-free networks, Physica A (2016), http://dx.doi.org/10.1016/j.physa.2016.11.011

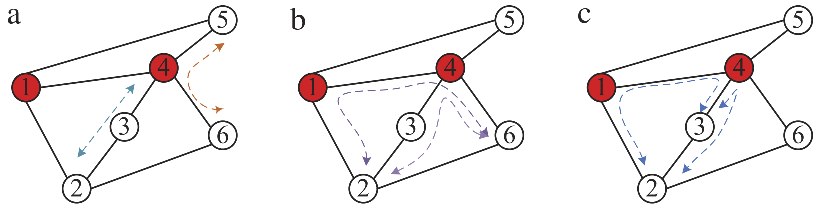

Fig. 1. (Color online). Examples for routing paths including check-in nodes (the filled ones with red color). There are many cases. (a) Along the shortest path, there is at least a check-in node included, such as $P_{5,6} = \{5, 4, 6\}$ in which node 4 is a check-in node. Along the shortest path, no check-in node included, $P_{2,6} = \{2, 6\}$ and $P_{3,2} = \{3, 2\}$ in (b) and (c) respectively.

occur frequently. Currently, a number of researchers focus on the routing optimizations [1–33] from different perspectives, including the efficient routing (ER) [2], optimal routing (OR) [3], global dynamic routing (GDR) [5], incremental routing (IR) [6], hybrid routing (HR) [10], etc. The results showed that the network performance can be significantly enhanced.

However, the previously proposed routing methods cannot be employed into all scenarios. In real networked systems, objects navigated in the networks have to pass through at least one of many specified nodes. For instance, in road networks, vehicles consume gas fuel and often need to pass through many gas stations to buy gas fuel. In the express delivery network, the trucks have to transfer many mediate stations for package collection or distribution with check-in records or GPS (Global Positioning System) trajectories. In communication networks, for security purpose, the source and routing path must be trusted ones, and especially under the source routing [34] mechanism, many mediate nodes are pre-assigned for packets to pass through. Here we call these nodes equipped with special functions as check-in nodes. In other words, there is a fraction of specified nodes acting special roles for objects to check in. Then the route of every object delivered in the networks cannot be simply assigned as the shortest path, because, along the shortest path, there may be no check-in node. Then an open problem arises. For every source and destination (different from the source) pair, assuming that the nodes of the delivery path including the source and destination must contain at least a check-in node, which routing algorithm can achieve high traffic capacity in such complex networked systems?

In this work, we try to design possible and efficient routing algorithms to satisfy such check-in demands. In the following part, we will introduce possible routing methods, traffic model and network model. Then extensive simulation results will be shown to confirm the effectiveness of the proposed methods. Finally, we close this work with a conclusion.

2. Routing strategy & models

2.1. Check-in based routing

In general, an efficient path between a pair of source s and destination d can be denoted as $P_{s,d} = s \equiv v_1, v_2, \ldots, v_l \equiv d$. Given a fraction of check-in nodes in the network, every efficient path must include at least a check-in node, denoted as $P_{s,d} = s \equiv v_1, v_2, \ldots, v_l \equiv d \exists v_i \in V^*, 1 \leq i \leq l$, where V^* is the set of all check-in nodes in the network. There are many cases by employing a given routing strategy such as the shortest path routing which can be computed by the *Dijkstra* algorithm [35] with time complexity $O(n^2)$. As shown in Fig. 1(a), the shortest path $P_{5,6} = \{5, 4, 6\}$ includes a check-in node 4, and this path satisfy the check-in transportation demand. In this case, the shortest path between this pair of source and destination can be directly used. Unfortunately, many shortest paths exclude the check-in nodes, such as $P_{2,6} = \{2, 6\}$ and $P_{2,3} = \{2, 3\}$ in Fig. 1(b) and (c) respectively. In order to achieve the goal of passing through check-in nodes, here we propose a general routing mechanism called check-in based routing (CBR) denoted as

$$P_{s,d} = \min\{P_{s,i} + P_{i,d}\}, \quad i \in V^*, \tag{1}$$

where $P_{s,i}$ and $P_{i,d}$ are two efficient paths respectively. $P_{s,i}$ and $P_{i,d}$ can be computed by different routing strategies. If uniquely employing the shortest path routing, as shown in Fig. 1(b), the path between node 2 and 6 might be $P_{2,6} = \{2, 1, 4, 6\}$ or $P_{2,6} = \{2, 3, 4, 6\}$ with equal path length. In this work, we assume there is only one path employed between a pair of nodes. If multiple equal length paths coexist, one of them is chosen randomly. In Fig. 1(c), the efficient path between node 3 and 2 might be $P_{3,2} = \{3, 4, 3, 2\}$, in which some nodes are visited more than once. We assume this case is allowed. Especially in road networks, it is a very common case for a car going to a gas station first and then pass through the source node to reach its destination.

2.2. Traffic model

Routing strategy can efficiently navigate an object from one place to another by following the CBR. Network model is the basic infrastructure that dynamic traffic takes place on. Traffic model reveals the dynamic traffic flowing progresses in the network. We regard every node as both host and router which can either generate packets or forward packets. Each node can deliver at most C (here, we set $C = 1$) packets to its immediate neighbors. At each time step, there are R packets generated in the network with randomly chosen sources and destinations. The First-In-First-Out (FIFO) discipline is used in

Please cite this article in press as: Z.-Y. Jiang, et al., Check-in based routing strategy in scale-free networks, Physica A (2016), http://dx.doi.org/10.1016/j.physa.2016.11.011