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Adaptive routing strategy on networks of mobile nodes

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HIGHLIGHTS

- We proposed an adaptive routing strategy for transportation on networks of mobile nodes.
- The routing strategy incorporates geographical distance with local traffic information through a tunable parameter.
- There exists an optimal value of the parameter, leading to the maximum traffic throughput of the network.

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ABSTRACT

The design of routing strategies for networks of mobile nodes has received increasing attention in recent years. In this paper, we propose an adaptive routing strategy that incorporates geographical distance with local traffic information through a tunable parameter h. It is found that there exists an optimal value of h, leading to the maximum traffic throughput of the network. The optimal value of h decreases as the moving speed increases and increases as the communication radius increases. The dependence of the throughput on the moving speed and the communication radius is also studied. Our results show that for a wide range of the parameters, the throughput decreases as the moving speed increases. However, when the value of the parameter is set to be one, the maximum throughput is obtained at a moderate speed. Moreover, we find that the throughput increases with the communication radius.

1. Introduction

Transportation processes are common in natural and engineering systems, examples of which include the transfer of information packets over the Internet, the motion of vehicles in urban road networks, and the migration of carbon in biosystems. In the past decade, the combination of complex network and transportation dynamics has attracted a growing interest [1–5]. Much effort has been devoted to improve the efficiency of transportation and avoid the emergence of traffic congestion [6–10]. To enhance the transportation capacity of a network, researchers have proposed various methods, such as the optimization of network structures [11–15], the improvement of routing strategies [16–23], and the rational allocation of node capacity [24,25].

In most previous studies, the transmission of data packets was implemented on static networks, in which nodes are immovable and links between them are changeless. However, transport systems consisting of mobile agents are becoming more and more important in the modern world. A typical example is the ad-hoc network [26], in which mobile nodes communicate with each other via wireless links and a node can transmit data packets to the other node if their distance is

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shorter than a critical value. So far, the transportation dynamics on networks of mobile nodes have attracted little attention in the physics community. Recently, we proposed a random routing to study the transportation dynamics on networks of mobile nodes [27]. In the random routing, each node performs a local search within a circle and the packet is forwarded to a randomly chosen node in the searched area. In this paper, we propose a traffic awareness protocol (TAP) that integrates the geographical distance with queue length to deliver packets on networks of mobile nodes.

The principle of TAP was first proposed by Echenique et al. [28,29] to study the information transmission on static networks. In the original TAP, a node l decides to forward a packet to a neighboring node i with the shortest effective distance $hd_{ij} + (1-h)n_i$ toward the destination j, where d_{ij} is the minimum number of hops between node i and j, n_i is the number of packets in the queue of i, and h is the traffic awareness parameter. It was found that $h \approx 0.8$ gives the best performance for scale-free networks. Stimulated by the pioneering work of Echenique et al., TAP and its variations have been widely studied in the past few years [30–32]. However, TAP has never been applied in dynamical networks before. To make TAP adapted to networks of mobile agents, we redefine d_{ij} as $d_{ij} = D_{ij}/r$, where D_{ij} is the geographical distance between node i and j, and r is the communication radius of each node. We have found that there exists an optimal value of h, leading to the maximum traffic throughput for networks of mobile nodes.

2. Model

In our model, N nodes move on a square-shaped cell of size L with periodic boundary conditions. Agents change their directions of motion θ as time evolves, but the moving speed v is the same for all nodes. Initially, nodes are randomly distributed on the cell. After each time step, the position and moving direction of an arbitrary node i are updated according to

$$x_i(t+1) = x_i(t) + v\cos\theta_i(t), \tag{1}$$

$$y_i(t+1) = y_i(t) + v\sin\theta_i(t), \tag{2}$$

$$\theta_i(t) = \Psi_i, \tag{3}$$

where $x_i(t)$ and $y_i(t)$ are the coordinates of node i at time t, and Ψ_i is an N-independent random variable uniformly distributed in the interval $[-\pi, \pi]$. The geographical distance between node i and j at time t is defined as

$$D_{ij}(t) = \sqrt{[x_i(t) - x_j(t)]^2 + [y_i(t) - y_j(t)]^2}. \tag{4}$$

Each node has the same communication radius r. Two nodes can communicate with each other if the geographical distance between them is less than r. Agent i's neighbors are defined as nodes who are within i's communication area.

At each time step, there are R packets generated in the system, with randomly chosen source and destination agents, and each agent can deliver at most C packets toward their destinations. To deliver a packet to its destination, an agent performs a local search within its neighbors. If the packet's destination is found inside the searched area, it will be delivered directly to the destination. Otherwise, the packet is forwarded to a neighboring node i toward its destination j with the smallest value of effective distance, denoted by

$$d_{eff}^{ij}(t) = h\frac{D_{ij}(t)}{r} + (1-h)\frac{n_i(t)}{C}, \tag{5}$$

where $n_i(t)$ is the number of packets in the queue of i at time t and h is the traffic-awareness parameter ($0 \le h \le 1$). If a node has no neighbors, it cannot deliver packets at that time. It is worth noting that when $h = 1$, the packet is delivered to a neighboring node whose geographical distance away from the destination node is the shortest.

The queue length of each agent is assumed to be unlimited and the first-in–first-out principle holds for the queue. Each newly generated packet is placed at the end of the queue of its source node. Once a packet reaches its destination, it will be removed from the system.

3. Results and analysis

In the following studies, we set the number of agents $N = 1500$, the size of the square region $L = 10$ and the node delivery capacity $C = 1$.

To characterize the transportation capacity of a network, we exploit the order parameter η introduced in Ref. [33]:

$$\eta = \lim_{t\to\infty} \frac{C}{R}\frac{\langle \Delta N_p \rangle}{\Delta t}, \tag{6}$$

where $\Delta N_p = N_p(t + \Delta t) - N_p(t)$, $\langle \cdots \rangle$ indicates the average over a time window of width Δt, and $N_p(t)$ represents the total number of packets in the whole network at time t. As the packet-generation rate R is increased through a critical value of R_c, a transition occurs from free flow to congestion. For $R \le R_c$, there is a balance between the number of generated and that of removed packets so that $\langle \Delta N_p \rangle = 0$, rendering $\eta(R) = 0$. In contrast, for $R > R_c$, congestion occurs and packets will accumulate in the system, resulting in a positive value of $\eta(R)$. The traffic throughput of a network can thus be characterized by the critical value R_c.