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Towards a Model for Information Traffic Flow in Wireless Networks

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Abstract. This paper presents a discrete stochastic model for information traffic flow through wireless networks. Many wireless nodes are powered by batteries. Thus, the number and buffer size of wireless nodes would greatly affect the performance of the system. The performance analysis is based on the throughput (J)-density (ρ) relationship. It is shown that the system may exist in one of three steady-state regions: low-density (LD), high-density (HD) and maximal-current (MC). In the MC region, the maximal throughput 0.5 is reached. The LD region corresponds to free flow; while the HD region is congested traffic with J=1-ρ. The simulation results suggest that throughput is related to the number of buffer size, but independent of the number of intelligent nodes.

Keywords: Wireless negtwor; Information traffic; Asymmetric exclusion process; Monte Carlo simulations

1. Introduction

Study on the wireless networks has received much attention from inside and outside academia in recent years. The ultimate goal of the wireless networks is to realize “anytime, anywhere” Internet communications. Many efforts have been made towards this goal and enhanced better understanding of the wireless networks. However, the irregular and heterogeneous topology of networks, the complicated transmission protocols, the collective behaviour of the users, the rapidly increasing wireless nodes and variant access demands (e.g., video streams) and the highly non-linear network dynamics combine together to build considerable complexity [1].

Due to the complicity of the Internet dynamics, it is difficult to analyze the performance (e.g., throughput and delay) of the wireless networks from theoretical point of view. Wireless nodes or routers (including transmission protocols) have been considered as bottlenecks for information traffic flow in the wireless networks. Therefore, the fundamental understanding of information traffic may help us improve the performance of the wireless networks. For this, mathematical models can reveal an integrated picture that shows how routers interact, and enables us to understand the evolution and transmission of traffic congestion patterns.

There have been many recent interests in packet transport in the Internet based on cellular automata (CA) such as in [2-6]. The analogies of computer network and highway traffic have been presented in [7-8]. These investigations suggest that cellular automata could be used to simulate Internet traffic. However, the effects of routers on the performance of the networks haven’t been better understood theoretically.

This paper studies a one-dimensional information traffic flow using totally asymmetric simple exclusion process (TASEP) which is a simplified version of CA. TASEP has been widely used to analyse non-equilibrium transport in Physics, Chemistry and Biology (e.g., vehicular traffic and molecular motor traffic) [9]. TASEP is a one-dimensional lattice model where particles move uni-directionally with hard-core

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exclusion (that is, each site can be occupied by at most one particle at any given time). With regard to information traffic in the wireless networks, information flow can be divided into data packets which correspond to particles in TASEP models. Wireless nodes and buffer size can be mapped into sites in TASEP models. The hopping probabilities of particles reflect the link reliability. The entry and exit in the TASEP models correspond to the source and the destination of the wireless networks.

This research may shed lights on multihop wireless networks (MWN). Existing buffering schemes for MWN may lead to buffer overflows and excessive queuing delay. Thus, the wireless network performance such as throughput and delay is not satisfied. Our simulation results may help design better buffering schemes for MWN. This paper is organized as follows. In Section II, the model is described. In Section III, we discuss the results of Monte Carlo simulations. We give our conclusions and areas for further investigation in Section IV.

2. The Model

In a wireless network, when a data file is transported from one end to the other end, the file will be divided into small packets and move through several routers. Once these packets arrive at the destination, they will be combined into one file. Thus, this kind of transport between two ends can be viewed as a one-dimensional non-equilibrium process. A simple information traffic with 3 routers (or wireless nodes) is shown in Figure 1(a). The buffer size for each router is assumed to be, e.g., 4 (it varies in the real world). p_1, p_2, p_3 and p_4 represent the corresponding network reliability or available bandwidth. For simplicity, we arbitrarily assume $p_1 = p_2 = p_3 = p_4 = 1$ in this paper, i.e., all links or bandwidths are perfect. Figure 1(a) can be mapped to a one-dimensional TASEP with long-range hopping, as shown in Figure 1(b).

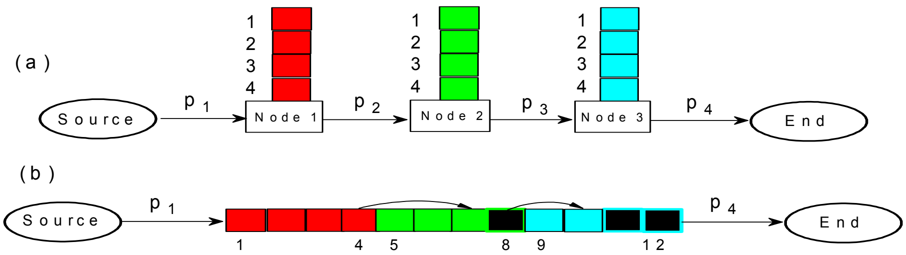

Figure 1. (a) An illustration of a simple information traffic through 3 routers (or wireless nodes). The buffer size for each node is assumed to be 4. p1, p2, p3 and p4 represent the corresponding connection status or available bandwidth. We arbitrarily assume p1 = p2 = p3 = p4 =1 in this paper. (a) can be mapped to (b) which is a one-dimensional TASEP with long-range hopping. The filled black squares mean that the sites are occupied by data packets.

The model is defined in a one-dimensional lattice of L sites with periodic boundary conditions. L = N*B (N is the number of nodes, while B is the number of buffer size in each node). An occupation variable, τ_i, is defined to denote the state of the ith site ($1 \leqslant i \leqslant L$). $\tau_i = 1$ (or $\tau_i = 0$) means that the ith site is occupied (or empty). The periodic boundary conditions are used in this paper. The following rules are applied to all sites in parallel: (1) If $\tau_i = 1$ and $i = m$*B ($m = 1,2,\cdots$), the packet at site i can move to site i+S ($1 \leqslant S \leqslant B$) provided the successive S sites from i+1 to i+B are empty. This rule can be understood as follows. Information flow obeys the FIFO (First-In-First-Out) rule. When a packet moves from the head of the queue in one node to the next node, it is still the head or adds to the tail of the other queue in the next node. This rule describes packet transport when they are the head of queues in nodes. In other words, this rule describes the motion of packets between two neighbouring nodes. (2) If $\tau_i = 1$ and $i \neq m$*B ($m = 1,2,\cdots$), the packet at site i can move to site i+1 provided the site i+1 is empty. This rule describes the motion of packets within a node. That is, packets can only move forward one site in each time step.

3. Simulation Results and Discussion

In this Section, the simulation results are presented and discussed. The fundamental diagram and density profiles are obtained from computer simulations. The fundamental diagram is also called flux-density relationship and widely used in studying vehicular traffic. Here we define the fundamental diagram as the throughput-density (i.e., J-ρ) relationship. Throughput (J) is defined as the average number of packets passing through a specific site per time step. The simulation results show that the flux of packet depends on the density of packet as well as the randomization probability. Figure 6 gives the flux of packet as the function of the packet density with different randomization probabilities. The density of the system is defined as the ratio of the number of packets to the number of sites, that is

$$\rho = M/L. \tag{1}$$

where M and L is the total number of packets and sites, respectively.

Initially, packets are randomly placed on the lattice with a uniform distribution. The packets then move from the left to the right following the above rules. In our simulations, the data for a transient time of 1×10^5 time steps are discarded. We gather data for 2×10^6 time steps. We first investigate the effect of buffer size on throughput. Figure 2 shows the fundamental diagrams with different number of buffer size and N = 5. It is found that the fundamental diagram can be divided into three regions: low-density (LD), maximal-current (MC) and high-density (HD) regions. In the LD region, throughput increases with the increase of density. The maximal throughput J = 0.5 is reached in the MC region. When ρ > 0.5, throughput decreases with the increase of density. It is also shown that upon increasing the number of buffer size, the LD region shrinks and the MC region expands, but the HD region is unchanged (see Figures 2(a-d)). Figure 2(d) shows the effect of the number of nodes on throughput, which implies that the throughput is independent of the number of nodes.

We then examine density profiles on the lattice. Although the system density is known (see Eq. 1), packet density at each site may be different. The packet density at each site can correspond to packet transport delay at each site. The successive packet densities within a node can correspond to a queue in a router. In the HD region (ρ > 0.5), our simulation results show that the packet density at each site is equal to the system density (see Figure 3). We then obtain the length of queue (Q) at each node: Q = ρ*B. In Figure 3, we set N = 10 and B = 50. The corresponding throughput J = 1- ρ.

Figure 4 shows the packet density at each site in the LD region with ρ = 0.1, N = 5 and B = 4. In this case, packets make a long-range hopping without congestion at the last site of each node. That is, packet density at other sites is equal to 0. Packet density at the last site of each node is equal to ρ*B = 0.1*4 = 0.4. Therefore, packet transport in this region is not delayed and the queue at each node is equal to 0.

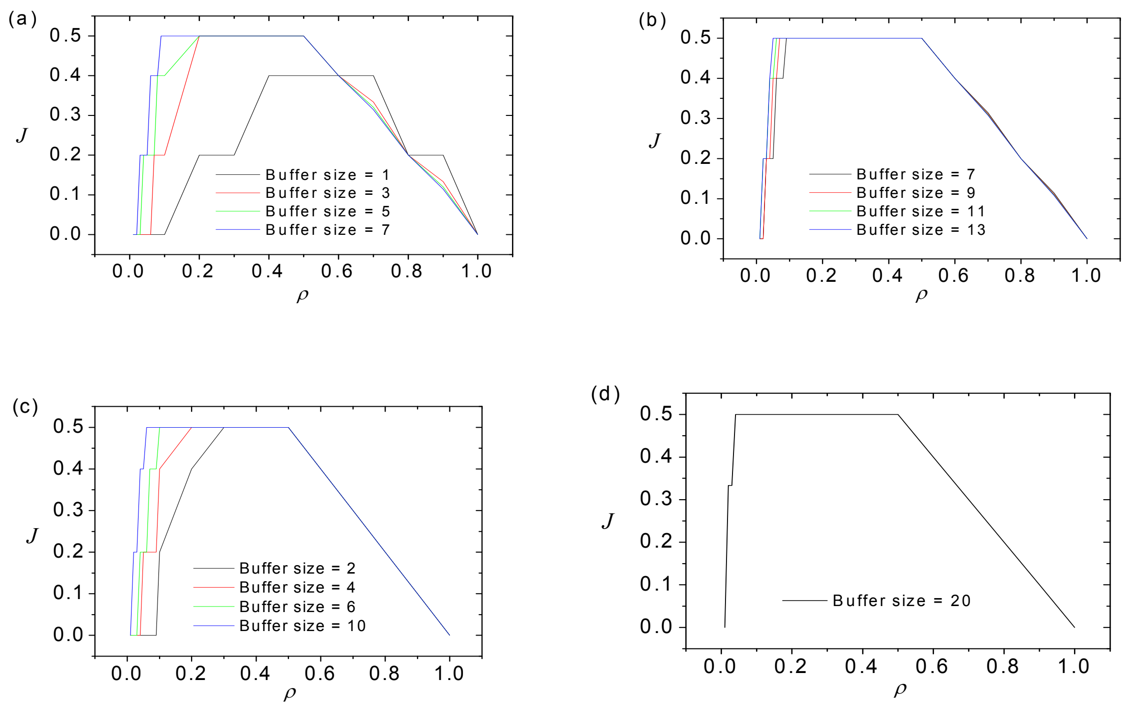

Figure 2. The fundamental diagrams with different number of buffer size and N = 5. (a) and (b) Buffer size is odd

number. (c) Buffer size is even number. (d) Buffer size is fixed and the number of nodes varies.

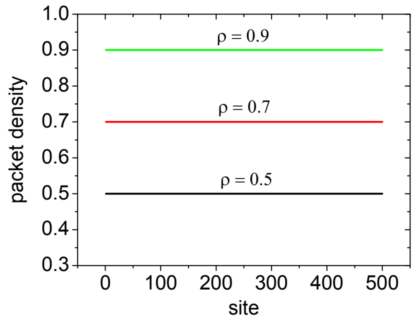

Figure 3. In the HD region, packet density at each site with different system density and N = 10, B = 50.

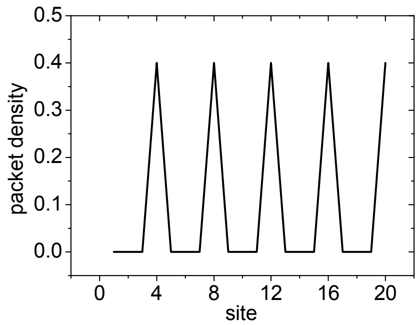

Figure 4. In the LD region, packet density at each site with system density ρ = 0.1 and N = 5, B = 4.

The MC region is between free flow (LD region) and congested flow (HD region). Although throughput $J = 0.5$ is identified, packet density at each site is complex. Figure 5 shows packet density for $\rho = 0.2$ and $\rho = 0.4$. It is found that the information traffic consists of congested flow (the first several and the last several nodes) and free flow. With the increase of ρ, the region of congested flow expends while the region of free flow shrinks (see Figures 5(a) and (b)). When $\rho = 0.5$, the free flow disappears.

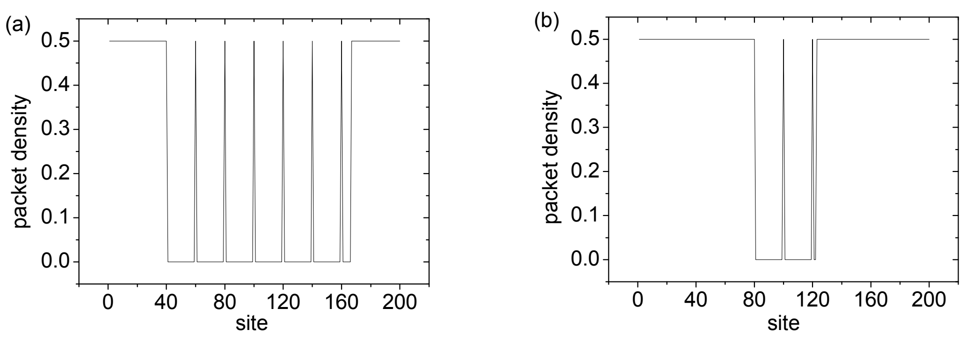

Figure 5. In the MC region, packet density at each site with N = 5, B = 4. (a) system density ρ = 0.2 and (b) system density ρ = 0.4.

4. Conclusions

This paper investigates a simple one-dimensional information traffic model in the wireless networks based on asymmetric exclusion process. The effects of the number of wireless nodes and the number of buffer size on traffic flow are simulated. The fundamental diagram (i.e., throughput-density or J-ρ relationship) is obtained. It is shown that the traffic may include three steady-state regions: low-density (LD), high-density

(HD) and maximal-current (MC). In the MC region, the maximal throughput 0.5 is reached. The LD region corresponds to free flow; while the HD region is congested traffic with J=1-ρ. Throughput is related to the number of buffer size, but independent of the number of nodes.

In this paper, we assume that all links between nodes are the best reliable. However, network links may be not always good or maximum throughput may not always hold in practice. Therefore, it is necessary to study the traffic dynamics when one or many links are not reliable. A theoretical mean-field analysis for the proposed model will be reported later. This simple model can be extended to describe more realistic information traffic in the wireless networks. The model also provides a visualized way to illustrate the information transformation in the wireless networks.

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