Physics Letters A 374 (2010) 516–521

Contents lists available at ScienceDirect

Physics Letters A

www.elsevier.com/locate/pla

Asymmetric exclusion processes with site sharing in a one-channel transport system

Mingzhe Liu [a], Ken Hawick [a,*], Stephen Marsland [b]

[a] Institute of Information and Mathematical Sciences, Massey University at Albany, Auckland, New Zealand
[b] School of Engineering and Advanced Technology, Massey University, Palmerston North, New Zealand

ARTICLE INFO

Article history:
Received 18 September 2009
Received in revised form 4 November 2009
Accepted 15 November 2009
Available online 21 November 2009
Communicated by R. Wu

Keywords:
TASEP
Mean-field approach
Monte Carlo simulations
Sharing mechanism

ABSTRACT

This Letter investigates two-species totally asymmetric simple exclusion process (TASEP) with site sharing in a one-channel transport system. In the model, different species of particles may share the same sites, while particles of the same species may not (hard-core exclusion). The site-sharing mechanism is applied to the bulk as well as the boundaries. Such sharing mechanism within the framework of the TASEP has been largely ignored so far. The steady-state phase diagrams, currents and bulk densities are obtained using a mean-field approximation and computer simulations. The presence of three stationary phases (low-density, high-density, and maximal current) are identified. A comparison on the stationary current with the Bridge model [M.R. Evans, et al., Phys. Rev. Lett. 74 (1995) 208] has shown that our model can enhance the current. The theoretical calculations are well supported by Monte Carlo simulations.

1. Introduction

The totally asymmetric simple exclusion process (TASEP) is a one-dimensional lattice model where particles move unidirectionally with hard-core exclusion (that is, each site can be occupied by at most one particle at any given time). The original TASEP was introduced in 1968 as a model of biopolymersation of ribosomes [1]. Recently, a great number of variants have been developed to model biological transport, such as in [2–8]. The model also finds applications in traffic simulations and other transport systems e.g., in [9–11]. Meanwhile, as a paradigm of driven diffusive systems, TASEPs have been investigated theoretically in their own right [12–24].

In these TASEP models, either single species of particles or multiple species, particles follow the *site-exclusion mechanism*, i.e., hard-core rule, on one channel or multiple channels of movement. The TASEP with *site-sharing mechanism* has not been well studied so far. We believe that the study on the TASEPs with site sharing is interesting and worthwhile theoretically and practically. In many realistic models component entities such as different species of particles do indeed share the same sites simultaneously and this multiple occupancy likely plays an important role in system properties. In fact, it is possible that different species particles can share the same site. For instance, when pedestrians walk along a narrow one-channel pathway in opposite directions and meet together, they may share a space, and then pass each other.

The proposed two-species TASEP model is based on the site-sharing mechanism. There is also a substantial literature on two-species ASEP models with a *particle-exchange* mechanism, e.g., under periodic boundary conditions [25–27] and open boundary conditions [12,28–31]. Evans et al. [12] firstly investigated two-species TASEP with a particle-exchange mechanism and open boundaries. Their model is known as the Bridge model. [29] studied an interesting case in which two-species of particles can be converted each other with a certain probability at boundaries. Popkov et al. [30] introduced the Bridge model with two junctions. More recently, Gupta et al. [31] extended the Bridge model to the relaxed case, that is, the particle-exchange mechanism is also applied to the boundaries. The basic stationary and dynamic properties of non-equilibrium systems with two-species of particles are reviewed in [32]. The spontaneous symmetry breaking (SSB) is observed and exhibited as high-density/low-density phase and/or asymmetric low-density/low-density phase in [12,25,28,30,31]. Physically one would expect that these models show a similar phase diagram and general behaviour since the details of the exchange mechanism (with or without site-sharing) are expected to be irrelevant.

In this Letter, we investigate a one-dimensional lattice model under open boundary conditions. In the model, two species of particles move in opposite directions and are allowed to share a site with a certain probability when they meet. We note that there are two major differences between our model and previous two-species TASEP models: (1) In the bulk, two species of particles may share the same site in our model, rather than exchanging

* Corresponding author.
E-mail address: k.a.hawick@massey.ac.nz (K. Hawick).

0375-9601/$ – see front matter
doi:10.1016/j.physleta.2009.11.055

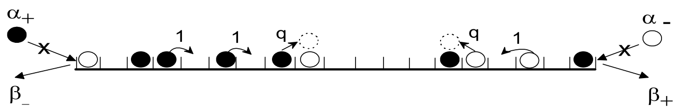

Fig. 1. Diagrammatical representation of a one-dimensional TASEP with two species of particles. The $(+)$ particles move from the left to the right, represented by filled circles, while the $(-)$ particles do the opposite movement, denoted by open circles. A site can be shared with probability q by two species of particles when they meet on the same lattice.

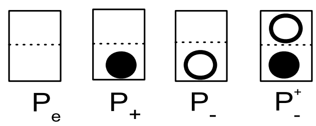

Fig. 2. Four possible states on each site. P_e, P_+, P_-, and $P_\pm$ denote corresponding probabilities.

each other in other models; (2) In the boundaries, our model allows two species of particles to share the same site as well, rather than excluding each other like in the Bridge model and its variants. Interestingly, when the boundary conditions of our model are the same as that of the Bridge model, the spontaneous symmetry breaking is observed. This work is now in progress and will be reported later.

This Letter is organized as follows. In Section 2, the model is described and mean-field theoretical analysis is conducted. In Section 3, we discuss the results of theoretical calculations and Monte Carlo simulations. A comparison is also made between our model and the Bridge model. We give our conclusions and areas for further investigation in Section 4.

2. The model and mean-field approximation

An illustration of a one-dimensional TASEP with two species of particles is shown in Fig. 1. The system includes N sites. Each site can be occupied by a $(+)$ particle and/or a $(-)$ particle, or empty. The $(+)$ particles move from the left to the right, represented by filled circles, while the $(-)$ particles (denoted by open circles) move in the opposite direction (see Fig. 1). In each time step, a site i is picked. At this site, a $(+)$ particle or a $(-)$ particle may be chosen. If a $(+)$ particle is chosen, one of the following rules is applied:

- In the bulk. (1) A $(+)$ particle at site i can hop to site $i+1$ with probability 1 if the target site is empty; (2) If the target site is occupied by a $(-)$ particle, the $(+)$ particle can share the site with probability q $(0 \leqslant q \leqslant 1)$; (3) If the target site is occupied by another $(+)$ particle, the $(+)$ particle stays at site i.
- In the boundaries. (1) A $(+)$ particle enters the left boundary with rate α_+ if the first site is empty, or with probability $q\alpha_+$ if the site is occupied by a $(-)$ particle; (2) A $(+)$ particle can exit the system from the last site at the right boundary with rate β_+.

If a $(-)$ particle is chosen, the similar rules are performed by $(-)$ particles from the right to the left. For simplicity, this Letter just discusses the case of $\alpha_+ = \alpha_- = \alpha$ and $\beta_+ = \beta_- = \beta$.

Since a site can be shared by two species of particles in our model, there are four possible states for each site: (1) occupied by a $(+)$ particle; (2) occupied by a $(-)$ particle; (3) occupied by both a $(+)$ and a $(-)$ particle; (4) empty. According to these states, we define four corresponding probabilities: $P_+(i), P_-(i), P_\pm(i)$, and $P_e(i)$ as shown in Fig. 2. Clearly, these probabilities can be normalised as:

$$P_+(i) + P_-(i) + P_\pm(i) + P_e(i) = 1. \tag{1}$$

The evolution equation of $P_\pm(i)$ over time can be given by

$$\begin{aligned} \frac{dP_\pm(i)}{dt} &= qP_\pm(i-1)P_-(i) + qP_+(i)P_\pm(i+1) \\ &\quad + qP_+(i-1)P_-(i) + qP_+(i)P_-(i+1) \\ &\quad - P_\pm(i)P_e(i+1) - P_\pm(i)P_e(i-1) \\ &\quad - qP_\pm(i)P_+(i-1) - qP_\pm(i)P_-(i+1), \end{aligned} \tag{2}$$

where the four positive terms represent the possible inflow for the formation of $P_\pm$ from site $i-1$ to site i for a $(+)$ particle and from site $i+1$ to site i for a $(-)$ particle. The four negative terms correspond to the possible outflow from site i. Similarly, the evolution of P_+ and P_- can be written as

$$\begin{aligned} \frac{dP_+(i)}{dt} &= P_+(i-1)P_e(i) + P_\pm(i-1)P_e(i) - qP_+(i)P_-(i+1) \\ &\quad - P_+(i)P_e(i+1), \end{aligned} \tag{3}$$

$$\begin{aligned} \frac{dP_-(i)}{dt} &= P_-(i+1)P_e(i) + P_\pm(i+1)P_e(i) - qP_-(i)P_+(i-1) \\ &\quad - P_-(i)P_e(i-1). \end{aligned} \tag{4}$$

We note that Eqs. (2)–(4) are not exact, but mean-field approximations. In steady state, these probabilities are expected to be independent of positions of sites. Thus, it is reasonable to neglect i indices in above equations. The above equations will tend to be zero in a stationary state, that is, $dP_\pm/dt = dP_+/dt = dP_-/dt = 0$, which leads to

$$qP_+P_- = P_\pm P_e. \tag{5}$$

The currents and bulk densities for $(+)$ particles and $(-)$ particles can be written as follows

$$J_+ = (P_\pm + P_+)(P_e + qP_-), \qquad \rho_+ = P_\pm + P_+, \tag{6}$$

$$J_- = (P_\pm + P_-)(P_e + qP_+), \qquad \rho_- = P_\pm + P_-, \tag{7}$$

where J_+ and J_- represent currents of $(+)$ particles and $(-)$ particles in the system, respectively. ρ_+ and ρ_- denote the corresponding bulk densities. The first term multiplier in the current expression in Eq. (6) represents the probability of finding a $(+)$ particle at a site, while the second term corresponds to the probability that the next site is available. The system is in left–right symmetry, and the dynamical rules are identical. Under the conditions where the symmetry of the system is retained, one expects that the currents of $(+)$ particles and $(-)$ particles should be equal.

When $J_+ = J_-$, one obtains $P_+ = P_-$ by comparing Eq. (6) with Eq. (7). Then by using Eq. (1), Eq. (5) can be rewritten as

$$qP_+^2 = P_\pm(1 - 2P_+ - P_\pm), \tag{8}$$

so that

$$P_+ = \frac{-P_\pm + \sqrt{(1-q)P_\pm^2 + qP_\pm}}{q}. \tag{9}$$

According Eqs. (1) and (9), Eq. (6) is given by

$$\begin{aligned} J_+ = \frac{1}{q^2}\Big((q-1)P_\pm + \sqrt{(1-q)P_\pm^2 + qP_\pm}\Big)\Big(q + 2P_\pm - 2qP_\pm \\ - (2-q)\sqrt{(1-q)P_\pm^2 + qP_\pm}\Big). \end{aligned} \tag{10}$$

In the low-density (LD) phase, the current of $(+)$ particles at the entrance of the left boundary is equal to

$$J_{LD}^+ = \alpha(P_e + qP_-). \tag{11}$$

According to the rule of current conservation in a steady state and comparing Eq. (11) with Eq. (6), we have

$$\alpha = P_\pm + P_+. \tag{12}$$

Eq. (12) means that the bulk density of (+) particles $\rho_+ = P_\pm + P_+ = \alpha$. Then according to Eqs. (9) and (12), we obtain

$$P_+ = \frac{1-\sqrt{1-4\alpha(1-q)(1-\alpha)}}{2(1-q)},$$
$$P_\pm = \frac{2\alpha(1-q)-1+\sqrt{1-4\alpha(1-q)(1-\alpha)}}{2(1-q)}. \tag{13}$$

Substituting Eq. (13) into Eq. (10), the system current in the LD phase reads,

$$J_{LD}^+ = \frac{\alpha}{2}\left(1-2\alpha+\sqrt{1-4\alpha(1-q)(1-\alpha)}\right). \tag{14}$$

In the high-density (HD) phase, the system dynamics is determined by exit rate β. The current for (+) particles at the right boundary is given by

$$J_{HD}^+ = \beta(P_\pm + P_+). \tag{15}$$

Applying the rule of current conservation, the following equation is derived from Eqs. (6) and (15)

$$\beta = P_e + qP_-. \tag{16}$$

As $P_+ = P_-$, according to Eq. (9), then

$$q(1-q)P_\pm^2 + \left(q^2+4\beta-4q\beta\right)P_\pm - q(1-\beta)^2 = 0. \tag{17}$$

The above equation has a solution

$$P_\pm = \frac{-(q^2+4\beta-4q\beta)+\sqrt{q^4+4(1-q)[q^2+\beta^2(2-q)^2]}}{2q(1-q)}. \tag{18}$$

P_+ can be obtained from Eq. (9)

$$P_+ = \frac{2q+2q^2\beta+4\beta-6q\beta-q^2-\sqrt{q^4+4(1-q)[q^2+\beta^2(2-q)^2]}}{2q(1-q)(2-q)}. \tag{19}$$

Thus, we can calculate the bulk density and current in the HD phase

$$\rho_{HD}^+ = \frac{q-2\beta}{2q} + \frac{\sqrt{q^4+4(1-q)[q^2+\beta^2(2-q)^2]}}{2q(2-q)},$$
$$J_{HD}^+ = \beta\rho_{HD}^+. \tag{20}$$

In the maximal-current (MC) phase, the current, J_{MC}, is independent of α and β, but is only determined by q. When J is maximal, Eq. (10) corresponds to $\frac{\partial J_\pm}{\partial P_\pm} = 0$ which leads to

$$\left[2q^2-3q-2(1-q)(4-3q)P_\pm\right]\sqrt{(1-q)P_\pm^2+qP_\pm}$$
$$+(1-q)(2-q)P_\pm\left[(1-q)P_\pm+q+\frac{1}{2}\right]-\frac{1}{2}q+1=0. \tag{21}$$

When q is known, $P_\pm$ can be solved exactly. Then we can calculate P_+, J_{MC}, and ρ_+ using Eqs. (9) and (10).

We then examine two extreme cases: $q=0$ and $q=1$. With regard to $q=0$, a (+) particle cannot share a site with a (−) particle, i.e., $P_\pm = 0$. Obviously, the system is blocked and system current $J=0$. Theoretically, $P_+ = 0.5$ and $P_- = 0.5$, which leads to $P_e = 0$ and $J_+ = 0$. As to $q=1$, a (+) particle does not distinguish between a (−) particle and a hole. And similarly for a (−) particle. The system is therefore decoupled into two independent TASEPs. Thus, system current J and density ρ satisfy: $J=\rho(1-\rho)$. According to Eq. (9), $P_+ = \sqrt{P_\pm} - P_\pm$. Then Eq. (6) is rewritten as

$$J_+ = \sqrt{P_\pm}(1-\sqrt{P_\pm}). \tag{22}$$

When the system is in the LD phase, comparing Eq. (22) with Eq. (11), one obtains $\sqrt{P_\pm} = \alpha$. The corresponding current in this phase can be read as $J = \alpha(1-\alpha)$. For the HD phase, comparing Eq. (22) with Eq. (15), we have $\sqrt{P_\pm} = 1-\beta$. Thus the current in the HD phase is equal to $J=\beta(1-\beta)$. In the MC phase, $P_\pm = 1/4$ can be derived from Eq. (21) when $q=1$. Then according to Eq. (9), we have $P_+ = 1/4$. Substituting values of $P_\pm$ and P_+ into Eq. (6), one obtains $J_+ = 1/4$ and $\rho_+ = 1/2$. It can be seen that the system for $q=1$ reduces to the standard one-dimensional TASEP with random update [13].

For another limiting case $\alpha_- = 0$, Eq. (1) is simplified as $P_+(i) + P_e(i) = 1$ (i.e., $P_\pm(i) = P_-(i) = 0$). The corresponding stationary current and bulk density for (+) particles can be represented as $J_+ = P_+P_e$ and $\rho_+ = P_+$ (see Eq. (6)). Thus, the model reduces to the standard TASEP. A proper mean-field theory for this case has been developed by Derrida et al. [13].

We next examine the possibility of observing spontaneous symmetry breaking in the system. Spontaneous symmetry breaking is characterized by unequal bulk densities of (+) particles and (−) particles under the symmetric structure and updating rules. There are six possibly asymmetric phases in the system, i.e., the (LD, LD), (HD, HD), (MC, MC), (LD, HD), (LD, MC), and (HD, MC) phases. The (LD, HD) phase means that (+) particles are in the LD phase, while (−) particles are in the HD phase.

In the (LD, LD) phase, J_{LD}^- at the entrance of the right boundary is given by

$$J_{LD}^- = \alpha(P_e + qP_+). \tag{23}$$

Comparing the equation with Eq. (7), one obtains $\alpha = P_\pm + P_-$. Similarly, we have $\alpha = P_\pm + P_+$ for (+) particles. We then derive $P_+ = P_-$, which contracts the assumption $P_+ \neq P_-$. Thus, the (LD, LD) phase does not exist in the system. Similarly, we can confirm nonexistence of the (HD, HD) phase.

For the (LD, HD) phase, according to Eqs. (6) and (7), $J_{LD}^+ - J_{HD}^- = qP_\pm(P_- - P_+) + P_e(P_+ - P_-) \neq 0$. If $J_{LD}^+ - J_{HD}^- > 0$, one has $qP_\pm > P_e$ as $P_- > P_+$. Then according to Eq. (16), $\beta = P_e + qP_+ < qP_\pm + qP_+ = q\alpha$. However, as (+) particles are in the LD phase, we have $\alpha < \beta$, which means $q\alpha < q\beta$. Thus, it leads to $\beta < q\alpha < q\beta$. This is impossible for $0<q<1$. In the similar way, we disconfirm the assumption $J_{LD}^+ - J_{HD}^- < 0$. Therefore, we conclude the (LD, HD) phase does not exist in the system.

As mentioned above, the MC phase is determined by $P_\pm$. The values of $P_\pm$ are the same for (+) particles and (−) particles in the system. Thus, the (MC, MC) phase reduces to the MC phase. If the (LD, MC) phase could exist in the system, $P_\pm$ in the LD phase should equal to that in the MC phase. However, $P_\pm$ only depends on q in the MC phase (see Eq. (21)), while it depends on q and α in the LD phase. Therefore, it is impossible that the (LD, MC) and (HD, MC) phases exist in the system. Therefore, only three stationary phases: LD, HD and MC are identified in this system, which are similar to the standard TASEP [13], but with shifted boundaries according to different sharing probability q. The phase diagram of the present model can be derived from the extremal principle proposed by Popkov and Schutz [33], which is expected to agree with the results obtained from the mean-field approximation in this Letter.

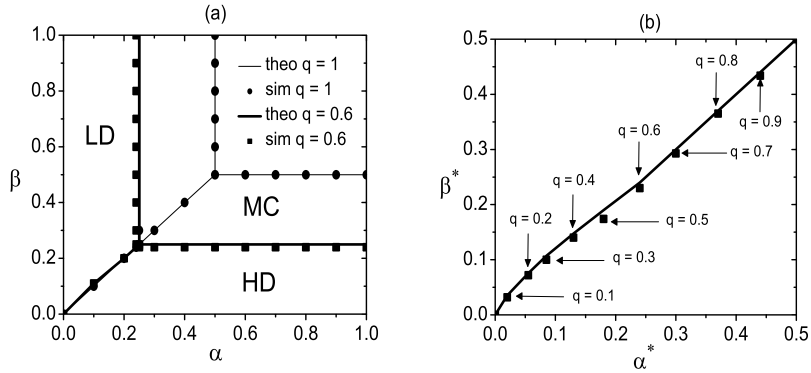

Fig. 3. (a) Phase diagram of the TASEP with two species of particles and sharing probabilities $q = 0.6$ and 1. (b) The critical points (α^*, β^*) with different q in the α–β plane. The solid line is for theoretical results, while the filled symbols correspond to simulation results. These figures are averaged over 10 runs.

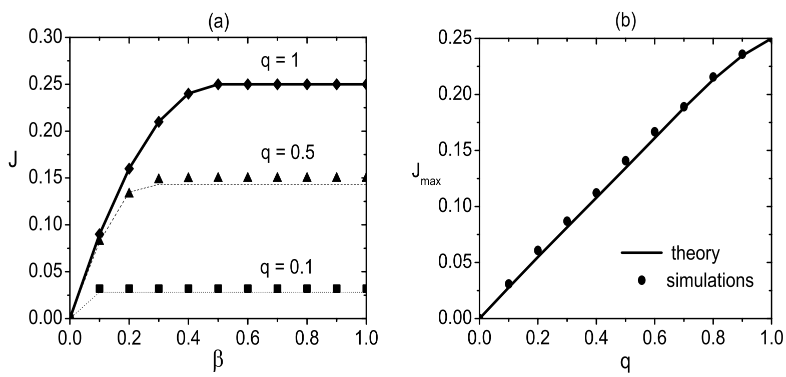

Fig. 4. (a) Currents obtained from theoretical calculations and computer simulations with $\alpha = 1$. (b) J_{max} versus q with $\alpha = 0.9$ and $\beta = 0.9$. The lines are for theoretical predictions, while the symbols correspond to simulation results. Data are collected by averaging 10 independent configurations.

3. Results and discussion

To verify the theoretical analysis above, Monte Carlo simulations were carried out. Open boundary conditions and random update were used with the system size $N = 1000$. For larger size N, our simulations show little deviations from those presented here. The first 1×10^9 time steps were discarded to let the transient out. The system current and density profiles were obtained by averaging 5×10^9 time steps. The system current J is defined as $J = J_+ = J_-$ and bulk density as $\rho = \rho_+ = \rho_-$, unless stated otherwise.

Phase diagrams obtained from theoretical predictions and computer simulations are presented in Fig. 3(a). By comparing the simulation results with theoretical calculations we conclude that the simple mean-field approach agrees well with simulations. However, there are still deviations from simulations for some values of q (see Fig. 3(b)). The simulations were repeated ten times with different random number seeds and the resulting critical points (α^*, β^*) are shown in Fig. 3(b). α^* and β^* in Fig. 3(b) are intersection points of the LD, HD, and MC phases. Thus, a phase diagram can be determined once a (α^*, β^*) pair is obtained. For example, the MC phase is specified by $\alpha \geqslant \alpha^*$ and $\beta \geqslant \beta^*$. Theoretical analysis of the model indicates that the phase diagram is similar to the normal TASEP [13], however, the phase boundaries are shifted according to different values of sharing probability q.

Current profiles in these phases with different q are investigated. For simplicity, we assume that α is fixed while β changes from 0 to 1. Fig. 4(a) shows the stationary current obtained from theoretical calculations and computer simulations for $\alpha = 1.0$. With the increase of β, a phase transition from the HD phase to the MC phase is observed in which the maximal current J_{max} is maintained and its value is determined by q. In Fig. 4(b), J_{max} versus different q is shown with $\alpha = 0.9$ and $\beta = 0.9$. It can be seen that the theoretical predictions are in agreement with computer simulations for $q = 1$, while they have slight deviations from simulation results (e.g., $q = 0.1$ and $q = 0.5$). The reason for this is probably due to neglecting the correlations between the two species of particles.

An interesting quantity in this study is $P_\pm$ which is the quantity that is new compared to previous one-dimensional two-species TASEP models. Thus, density profiles (denoted by P_+, P_-, $P_\pm$, P_e) in the LD, HD and MC phases can be obtained from theoretical predictions and computer simulations and have shown in Fig. 5. It is seen that theoretical results of P_+, P_-, $P_\pm$, P_e agree well with computer simulations when the system is in the LD or HD phase (see Figs. 5(a–b)). However, when the system is in the MC phase, only P_+ and P_- show a good agreement with simulation results. Large deviations can be found in $P_\pm$ and P_e (see Fig. 5(c)). For a better understanding of the MC phase, Fig. 5(d) shows the bulk density of (+) particles in the MC phase, i.e., $\rho_+ = P_+ + P_\pm$. One can see that the theoretical results of the bulk density agree qualitatively with simulation results when the system is in the MC phase.

The relationship among P_+, P_-, $P_\pm$, P_e and α is simulated and shown in Fig. 6. For simplicity, we arbitrarily set $\beta = 1$ and α changing from 0 to 1. In this case, the phase transition from the LD phase to the MC phase is observed. In the MC phase, P^+_- is determined by sharing probability q, independent of α and β. With the increase of q, P_e increases in the MC phase. Upon increasing to $q = 1$, $P_+ = P_- = P_\pm = P_e = 0.25$ (see Fig. 6(d)). On the other hand, when increasing q, the region of the MC phase shrinks while the region of the LD phase expands (see Fig. 3(a) and Figs. 6(a–d)).

A comparison of the average currents is also made between our model and the Bridge model under the same parameters in Monte Carlo simulations. Taking the flipping phenomenon into account in the Bridge model, we use the average current of (+) and (−) par-

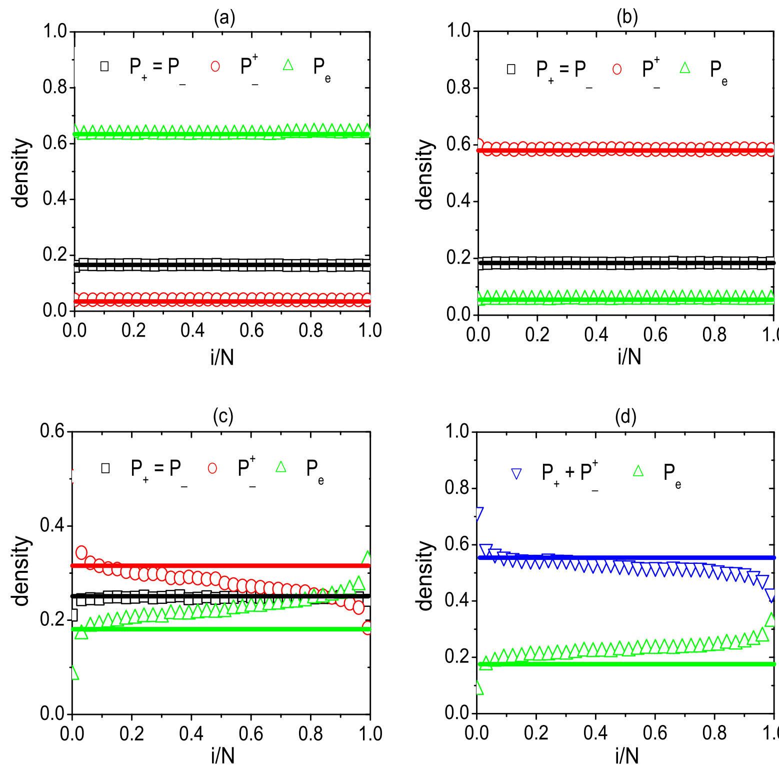

Fig. 5. (Color online.) Density profiles (P_+, P_-, $P_\pm$, P_e) in the LD, HD and MC phases obtained from theoretical predictions and computer simulations. Symbols represent the simulation results, while the corresponding thick lines are for the theoretical calculations. (a) LD phase with $\alpha = 0.2$, $\beta = 0.8$ and $q = 0.8$. (b) HD phase with $\alpha = 0.8$, $\beta = 0.2$ and $q = 0.8$. (c) and (d) MC phase with $\alpha = 0.8$, $\beta = 0.8$ and $q = 0.8$. (d) Bulk density of (+) particles in the MC phase, i.e., $\rho_+ = P_+ + P_\pm$.

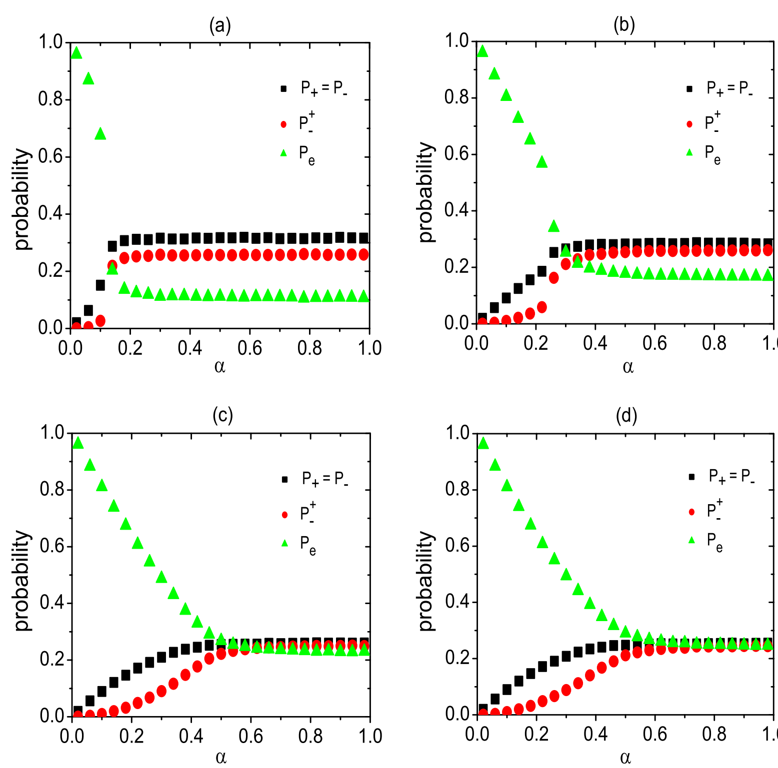

Fig. 6. (Color online.) P_+, P_-, $P_\pm$ and P_e versus α with $\beta = 1$ and different q. (a) $q = 0.3$, (b) $q = 0.6$, (c) $q = 0.9$ and (d) $q = 1$.

ticles here, i.e., $J_{ave} = (J_+ + J_-)/2$, where J_+ and J_- are currents of (+) and (−) particles, respectively. It is assumed that $\alpha = 0.2, 1$, $q = 0.3, 0.6, 0.9$ while β changes within $[0, 1]$ so that we can observe the average current in all possible phases. It is shown that our model can enhance the average current than that in the Bridge model (see Fig. 7). The reason for this is probably due to the relaxed boundary conditions and the site-sharing mechanism used in our model.

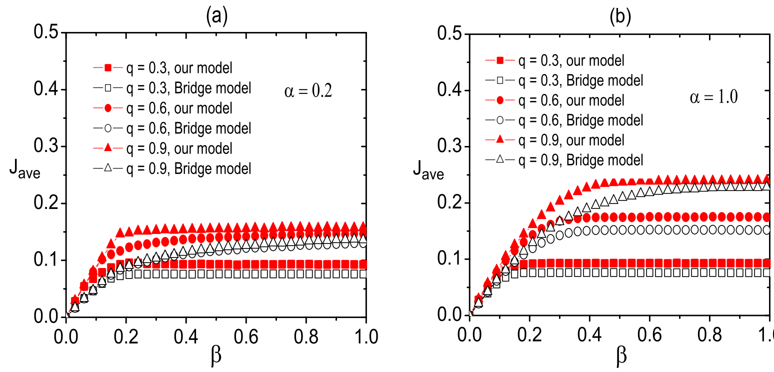

Fig. 7. (Color online.) A comparison on the stationary currents between our model and the Bridge model with different β in simulations. J_{ave} is the average current of $(+)$ and $(-)$ particles, i.e., $J_{ave} = (J_+ + J_-)/2$. The red filled symbols correspond to our model, while the black open symbols are for the Bridge model. (a) $\alpha = 0.2$ and (b) $\alpha = 1.0$.

4. Conclusion

This Letter studied the dynamics of two-species TASEP with site sharing in a one-dimensional system under random update and open boundary conditions. Hard-core exclusion is only applied to the particles of the same species, while different species of particles may break the hard-core exclusion, that is, they can share the same site with a certain probability q. The site-sharing mechanism is applied to the bulk as well as the boundaries. This kind of sharing mechanism has been little studied so far, to the best of our knowledge. The steady-state phase diagrams, currents and bulk densities are obtained using a simple mean-field approximation and extensive Monte Carlo simulations. Three stationary phases (low-density, high-density and maximal current) are identified with shifted phase boundaries, compared to the standard TASEP [13]. The phase boundaries depend on q. In the MC phase, currents and density profiles are dictated by q. We also compared our model with the Bridge model. It is shown that our model can enhance the current. Our theoretical predictions are supported by computer simulations.

Our work shows that the sharing mechanism of two species of particles is an interesting issue and needs to be further investigated. Our model can be extended to a more general case where particles can randomly attach to or detach from the lattice. It would be interesting to study the present model with parallel updating procedure.

Acknowledgements

The authors are grateful to anonymous referees for their valuable comments and suggestions.

References

[1] J.T. MacDonald, J.H. Gibbs, A.C. Pipkin, Biopolymers 6 (1968) 1.
[2] T. Chou, G. Lakatos, Phys. Rev. Lett. 93 (2004) 198101.
[3] S. Klumpp, R. Lipowsky, Phys. Rev. E 70 (2004) 066104.
[4] K. Nishinari, Y. Okada, A. Schadsschneider, D. Chowdhury, Phys. Rev. Lett. 95 (2005) 118101.
[5] D. Chowdhury, A. Schadsschneider, K. Nishinari, Phys. Life Rev. 2 (2005) 318.
[6] R. Lipowsky, Y. Chai, S. Klumpp, S. Liepelt, M.J.I. Müller, Physica A 372 (2006) 34.
[7] A. Morozov, E. Pronina, A.B. Kolomeisky, M.N. Artyomov, Phys. Rev. E 75 (2007) 031910.
[8] J.J. Dong, B. Schmittmann, R.K.P. Zia, Phys. Rev. E 76 (2007) 051113.
[9] D. Chowdhury, L. Santen, A. Schadschneider, Phys. Rep. 329 (2000) 199.
[10] J. Otwinowski, S. Boettcher, J. Stat. Mech. (2009) P07010.
[11] S. Srinivasa, M. Haenggi, TASEPs: A Statistical Mechanics Tool to Analyze the Performance of Wireless Line Networks, IEEE/ACM Transactions on Networking, 2009, submitted for publication.
[12] M.R. Evans, D.P. Foster, C. Godreche, D. Mukamel, Phys. Rev. Lett. 74 (1995) 208;
M.R. Evans, D.P. Foster, C. Godreche, D. Mukamel, J. Stat. Phys. 80 (1995) 69.
[13] B. Derrida, E. Domany, D. Mukamel, J. Stat. Phys. 69 (1992) 667.
[14] A.B. Kolomeisky, J. Phys. A 31 (1998) 1153.
[15] N. Rajewsky, L. Santen, A. Schadschneider, M. Schreckenberg, J. Stat. Phys. 92 (1998) 151.
[16] J. de Gier, B. Nienhuis, Phys. Rev. E 59 (1999) 4899.
[17] G.M. Schütz, in: C. Domb, J.L. Lebowitz (Eds.), Phase Transitions and Critical Phenomena, vol. 19, Academic Press, San Diego, 2001.
[18] G. Lakatos, T. Chou, J. Phys. A 36 (2003) 2027.
[19] A. Parmeggiani, T. Franosch, E. Frey, Phys. Rev. Lett. 90 (2003) 086601.
[20] F.H. Jafarpour, Phys. Lett. A 326 (2004) 14.
[21] P. Pierobon, M. Mobilia, R. Kouyos, E. Frey, Phys. Rev. E 74 (2006) 031906.
[22] R. Wang, M. Liu, R. Jiang, Phys. Rev. E 77 (2008) 051108.
[23] M.E. Foulaadvand, A.B. Kolomeisky, H. Teymouri, Phys. Rev. E 78 (2008) 061116.
[24] M. Liu, R. Wang, R. Jiang, M.B. Hu, Y. Gao, Phys. Lett. A 373 (2009) 195.
[25] P.F. Arndt, T. Heinzel, V. Rittenberg, J. Stat. Phys. 97 (1999) 1.
[26] K. Mallick, S. Mallick, N. Rajewsky, J. Phys. A 32 (1999) 8399.
[27] M.R. Evans, Y. Kafri, E. Levine, D. Mukamel, J. Phys. A 35 (2002) L433.
[28] E. Levine, R.D. Willmann, J. Phys. A 37 (2004) 3333.
[29] F.H. Jafarpour, Physica A 358 (2005) 413.
[30] V. Popkov, M.R. Evans, D. Mukamel, J. Phys. A 41 (2008) 432002.
[31] S. Gupta, D. Mukamel, G.M. Schütz, Robustness of spontaneous symmetry breaking in a bridge model, arXiv:0908.2571.
[32] G.M. Schütz, J. Phys. A 36 (2003) R339.
[33] V. Popkov, G.M. Schütz, Europhys. Lett. 48 (1999) 257.