Stochastic dynamics on graphs and congestion in transport systems: predictive models and application to urban mobility

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Transport systems are ubiquitous in biological and social systems [1] and their optimization is one of the key issue for the sustainability of the future cities. To highlight universal statistical properties of transport systems that can be directly related to generic properties of the particle dynamics or the structure of the underlying transport network is a fundamental step to detect the behavioral aspects of the individual performing the mobility [2]. The simple stochastic dynamical systems on graphs like random walks are analytical tools to study transport systems assuming that the flows on the link depend on the dynamical states of the connected nodes (Markov Random Field). The relation between the graph structure and the dynamical properties of the considered systems gives the possibility of detecting the rising of congestion phenomena and of defining monitoring and control strategies on transport networks [3]. We consider linear and non-linear diffusion models on graph with different topological structures, and we show that the dynamic susceptibility of the stationary states can be used to reduce the network dimensionality by a node clustering mechanism, and to optimize a monitoring procedure able to detect local failures in high flow links. In this way we succeed to monitor the network state by a limited number of 'sensor nodes' and we show that the proposed methods have better performance than the usual clustering procedures base on the network topology features. The presence of nonlinear effects in the dynamics may induce the formation of congested states starting from the drop in the transport capacity along a link. Our approach provides an early warning for the congestion formation in presence of a particle knowledge of the network state. We also study the correlation properties of the fluctuations due to the finite size effects [4] to introduce a measure of the system predictability using the concept the entropy production. The possible applications of the previous results to urban mobility is considered by using GPS data from mobile phones that allow the reconstruction of individual trajectories. We discuss the possibility of realizing data-driven models for a sustainable mobility in a smart city and the possible contributions to the development of a digital twin for a city.

References

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