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Determining the complexity of multi-component conformal systems: A platoon-based approach

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HIGHLIGHTS

- Platoon-based formations are discussed through nonextensive thermostatistics.
- The limit values of Tsallis q index for vehicular platoon formation are proposed.
- Superstatistics approach is utilized to obtain Tsallis q index.

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ABSTRACT

Many systems in nature and engineering are composed of subsystems. These subsystems may be formed in a linear, planar or spatial array. A typical example of these formations is a chain of vehicles known as platoon formation in traffic flow. Platoon formation of vehicles is a linear or planar formation of vehicles where a certain and a constant headway, and sideway if applicable, is provided in between every and each one of them. It is argued in this paper that a well-automated platoon formation of vehicles is an extreme case of conformity. During this transformation from a many degrees of freedom formation to a solid object, Tsallis q value is computed to be ranging from one extreme case of $q = 3$ to the other where $q = 1$, when classified in terms of inverse temperatures of clearance fluctuations. At one extreme of $q = 3$, one observes unbounded fluctuations in clearance fluctuations so that inverse temperature distributions approach a Dirac delta at the origin. At the other extreme of $q = 1$, fluctuations in clearance tend to zero asymptotically, where a solid structure of agents (vehicles) emerges. The transition from $q = 3$ to $q = 1$ is investigated through synthetic and experimental clearance fluctuations between the cars. The results show that during the transition from $q = 3$ to $q = 1$, the platoon loses its many degrees of freedom (*dof*) of motion until a solid single object emerges. Authors assert that the Tsallis q value of a platoon of vehicles is limited to $3 > q > 1$.

1. Introduction

Traffic flow is a complex, many particle system where vehicles come into contact, forming possibly long-range, non-Markovian type memory, where the dominating form of thermostatistics is the nonextensive entropic domain, instead of the highly idealized Boltzmann–Gibbs (BG) framework. The existence of such interactions has been shown in detailed analysis

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in [1,2]. Unless interactions are ignored, and simplified, traffic flow would hardly harbor Gaussian distributions, and ergodic time series.

Since resources in traffic are quite limited, the general tendency is to have a broader cooperation among the vehicles so that large groups of vehicles are commonly controlled and moved, avoiding jams, hoping to improve the overall efficiency of the traffic infrastructure. This coordinated and harmonious motion of vehicles is meant to have a better control of the highway traffic, directed to such amenities as fluent traffic, fuel economy, automated control of vehicles, etc. One such push is by a platoon formation where the vehicles are formed in a planar array, as well as a linear fashion. A prescribed distance is provided for each inter-vehicle clearance, and this distance and the speed of the formation are intended to be kept constant throughout and their corresponding fluctuations (errors) should be kept as small as possible. One may discuss the errors in either the speed, headway, sideway, or some of these variables for a given platoon formation. As the system is better controlled, the headway fluctuations, for example, is expected to subside, giving way to an almost constant specified headway distance. As the mean of the inverse variance and the variance of the inverse variance obtained from the errors in clearances tend to zero, it is seen that, with an idealized many body system, pdf of the inverse variance approaches the Dirac delta function.

The current traffic platoon formation literature has brought about multifarious topics, covering a wide range of issues. The major drive behind the platoon formation research has been an efficient and well-orchestrated traffic flow. Typical examples of the literature on the vehicular traffic platoon have concentrated on such topics as the stability [3–6], management and control [7,8], signal timing [9–11], safety, fuel consumption [12,13].

Of these traffic platoon literature for example the study [8] reviews some of the existing approaches to vehicular formation control under leader–follower approach and virtual leader approach, and in the paper the authors point to the importance of formation control in cooperative systems. The objective in their study is to design a feedback-based protocol for connected autonomous vehicles considering the different network topologies of initial states. Lyapunov technique is utilized to analyze the stability and consensus of the control protocol.

Another representative recent study for platoon management protocol could be [7] where the management is based on wireless communication. The protocol is designed under three maneuvers i.e. merge, split, and lane-change. The fuel consumption issue is addressed in many studies such as [13]. The authors consider a platooning problem in connection with minimizing the fuel consumption of the trucks, and the optimal platoon routing is studied in the paper. The study [14] deals with the multi- platoons-based cooperative driving and the inter-vehicle communication is the main concern in the study. The consensus based control algorithms are proposed for the vehicle platooning formulation. More than one platoon are considered and the results on inter and intra-platoon performances e.g. position and speed errors are evaluated for the system performance in the paper.

In another recent work [15] for the string stability problem of vehicle platoon, a collision prevention pre-compensation algorithm is proposed. The effectiveness of algorithm is tested by several simulation experiments. In the algorithm, such inputs as acceleration, deceleration, speed, time delay of vehicle-to-vehicle communication are introduced.

In the study of [16], the authors concentrated on two models of platoon formation over traffic flow breakdown at an expressway bottleneck, and speed transitions for a given platoon. Their traffic flow model considers the stochastic and dynamic processes of the traffic at the bottleneck. In their models probabilistic nature of traffic is investigated and, for example, for the speed transitions, Markov chain model is applied and on a bottleneck section of a single lane expressway, their combined platoon-based traffic flow model estimates the breakdown probability in regard to given flow rate.

The study of [5] deals with intra-platoon information management strategies, and in the study the platoon string stability is handled under the effects of communication delays. For the string stability in the platoon inter-vehicle communication is needed where the wireless communication is utilized. Five information updating schemes are proposed in which the leader vehicle conveys the data to its precedents and finally the simulation scenarios were also implemented.

In another work [6], the authors propose leader-following consensus algorithm to satisfy the string stability over the platoon of the vehicles. Spacing error is the main concern in the algorithm and it is computed between each vehicle and its neighbors. The simulation results cover the relation between both link probability and platoon size with error propagation, and the different communication graphs are also given for their algorithm.

The Ref. [17] studies N identical particle (vehicles) on a circle, and deals with thermal equilibrium spacing distributions. Hamiltonian function is performed to describe the energy of the system. Spacing between neighboring vehicles, and velocity values of the vehicles are processed via a Hamiltonian function. However, the interactions are considered to be short-range, and the generalized thermostatistics approach is not discussed as in [18].

As one may easily notice, the related platoon literature governs for example, the inter-vehicle communication, stability, fuel consumption, control, etc. in traffic flow. In this paper, the cooperation in platoon formation is discussed through a broader framework i.e. nonextensive thermostatistics. No references in literature could be found addressing the platoon formation problem via nonextensivity, and to the best knowledge of the authors, this is the first time nonextensive thermostatistics is applied to the platoon formation in the literature. We propose an upper and a lower limit of Tsallis q entropic index for platoon formations of interacting and cooperating agents. The authors first investigate the vehicular traffic platoon formation through a hypothetical scenario, and clearance errors are examined for the transition in the q values. Then, a platoon of three vehicles is devised, equipped with ultrasonic range sensors, data acquisition cards and on-board data loggers. The synthetic and experimental findings are compared and later, results are discussed. The authors elaborate this so-called upper and lower limit theoretically in Section 3, whereas in Section 4 the authors utilize the superstatistics