Developing Decentralized and Coordinated Surface Traffic Control Based on Well-Connected Smart Transportation Systems

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Surface Transportation systems (shortened as transportation systems hereafter) have significant direct impacts on the nation's productivity, environment, and energy consumption. To improve the performance of our transpiration systems, many advanced wireless communication, portable computational facilities, advanced sensing, and digital devices have been constantly brought into transportation infrastructures, such as individual cars, buses, trucks, trains, roadside sensors, signals, roadside E-board, etc. Thus, a well-connected smart transportation system, which enables communication among vehicles; between vehicles and the infrastructures; and among vehicles, infrastructures, and wireless devices, has merged and is still rapidly growing. In a smart transportation system, discrete transportation entities, equipped with built-in communication and computation functionalities, can not only interact directly or indirectly with each other but also and carry out relatively complicated computations and logic operations. Therefore, these entities, including smart vehicles, transportation infrastructures, and transportation operation agencies, form a highly distributed, self-organized, complex system. This modern transportation system enables ample promising applications of transportation cyber-physical systems (CPS) along with many fundamental research challenges, regarding how to model and describe such complex systems and how to optimize the performance of such systems to achieve system mobility, safety, and sustainability, and make surface transportation safer, smarter, and greener and ultimately enhance urban livability.

The state of the art shows that many existing transportation CPS research mainly focus on individual transportation entities such as individual vehicles, individual traffic signals, and individual parking lots. Accordingly, various advanced applications are developed, such as driver assistance systems to improve vehicle driving safety, including adaptive cruise control, lane departure warning, and early warning of road hazard, cooperative lane change. However, it is also noticed that many transportation smart entities can not only sense and find out intelligent action for their own functions, they can also exchange information with other smart entities and come out proper coordination actions. Taking smart signals as an example, they have been enabled to sense the incoming traffic flow from different directions and/or waiting in different lanes through its own sensing functionality or information exchange with other nearby traffic facilities (such as smart vehicles, loop detector, other traffic signals and so on), and further conducts real-time adaptive traffic control to minimize the average waiting time or maximize throughput of a corridor or network by adaptively adjusting their cycle/phase length and/or coordinating with other signals according to the observed traffic condition.

Motivated by the above view, this statement proposes transportation CPS research over a flock of smart entities in well-connected smart transportation systems. We seek to perform elegant mechanism control over a flock of smart vehicles (or a set of smart infrastructures) taking advantage of their cyber capabilities so that the goals of traffic mobility, safety, and sustainability can be achieved. More exactly, proper mechanism and implementation algorithms will be developed so that the interactions among smart transportation entities can be loosely controlled in a distributed and self-organized fashion, to ensure desired collective behavior, by integrating advanced tools from control theory, optimization, communication, computation, and transportation sciences. The proposed decentralized and coordinated traffic control can be establish on both physical traffic infrastructures and travelers. However, they have to be treated very differently in both modeling and control methodologies, because traffic operation agencies may have complete control on physical traffic infrastructures, but not on the travelers who are more independent and autonomous, while both of them can be considered as cognitive agents in smart transportation systems, and they both impact traffic mobility, safety, environmental friendliness. Thus two branches of advanced research are expected to be comprehensively investigated under the theme of establishing decentralized and coordinated traffic control over well-connected smart transportation systems integrating cyber technologies

As working on the systems consisted of smart traffic infrastructures, we will develop methods so that smart transportation infrastructures can seamlessly share their own perceived information, and find out the best operational decisions based on the shared information in a distributed fashion. Still taking smart traffic signals as an example, coordinated and distributed algorithms can be developed and implemented on smart traffic signals to realize adaptive reaction to traffic flow at the intersection they are located, and further conduct traffic control coordination among multiple signals in a corridor or network. Green wave signal timing is the nascent research of these vision. Similar idea can be expanded to many other traffic control infrastructures such as toll way, parking and so on. Classic control theories combined with operation research approaches, communication theories, algorithm design technologies, etc will be employed to reach this goal.

As working on the system consisted on smart vehicles driven by travelers, it is a different story compared to traffic infrastructures. Considering characteristics of individual travelers in traffic flow, usually proper mechanisms rather than mandatory behavior controls are preferred so that the system mobility and safety can be improved while the drivers will still follow their own behavior nature. An example of this approach can be routing guidance systems. While the drivers are selfish in this respect, meaning that they seek their own user optimality, we aim to design mechanisms which allow the drivers to “negotiate” with others before deciding their routes so that they can resolve their conflicts in competing on the limited traffic resources in a self-organized, distributed fashion, and at the same time lead them to follow certain desired collective behavior that improves the system level performance. Regarding the desired collective behavior, we may consider a comprehensive objective including safety, mobility, environmental friendliness, and so on. These objectives do not always align with each other, and they possess different level of importance in different transportation applications. Therefore, the traffic control system needs to carefully balance all these different objectives. Some major tools include optimization, game theory, distributed algorithm design, multi-agent control theories, and so on will be applied to address the traffic control targeted at travelers.

Overall, this statement proposes to extend the research of transportation CPS to a broader scope. The future research may work on a flock of smart entities rather than only focus on individual smart entities in transportation systems. The future research may program a flock of self-organized smart entities together to achieve a desired collective action rather than only make individual smart entities act intelligently for their own functions or local optimality. As more advanced cyber capability such as communication and computational devices are integrated into transportation facilities, to implement well-connected, information-rich smart transportation system will become near. This promising modern transportation systems will enable more efficient decentralized and coordinated control to be widely established, which will further open a new diagram of transportation CPS applications to strongly sustain the safety, mobility and sustainability of our transportation systems.