Smart Cities and Control

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IEEE CSS, through its new TC on Smart Cities founded as recently as December 2014, has launched an energetic initiative seeding new control sciences at urban and semi-urban scales. The story of city engineering, as old as cities themselves, has historically been one of concentration. Engineers have created water, transportation, and energy networks built to concentrate the food and natural resources of a vast hinterland into a dense urban population center. However, neither the concentration capacity of the great aqueducts of Rome nor the vast expressways of modernity define the cities of the future any longer.

The CSS Smart Cities Initiative is tuned to our age of global warming, urban heat islands, and ocean acidification. The most virtuous water network might well be the one bringing in only 2% of consumption, because the smart city would be efficiently re-converting and recycling the other 98% (see direct potable reuse[1]). In-situ micro-energy generation via wind or solar may be preferable to energy sourced from distant mines of coal or fields of gas. The urban food network is now castigated for consuming an unacceptable 9 calories to put 1 calorie on an urban plate [1]. Even the highway network transporting us is under pressure as drivers license acquisition rates fall for the first time since the birth of the automobile[2], the rise of automated cars fundamentally enhances the economics of car-sharing[3], and cities experiment with drones and personalized rapid transit like Lyft, or Uber.

The old urban engineering of concentration is giving way to a new smart engineering of conservation and local production. The CSS Smart Cities Initiative is geared to build its control sciences. Our style is feedback control moving shared automated cars in real-time to meet mobility demands or to modulate demand itself by dynamic pricing [2]. Smart cities should escape a personal car ownership model filling streets with cars, 96% of which are parked at any given time. Smart cities seek control in the mobility and energy nexus to realize Vehicle-to-Grid, or control to break the wasteful positive feedback between air-conditioning and urban temperature[4]. Building HVACs regulate a set interior temperature. Might it be possible to cut the temperature of an urban heat island by 1^{o}C through the coordinated control of a city's water, transportation and energy systems? Given that 50% of the world's population lives in urban regions, critical infrastructures of transportation, energy, healthcare, and food as well as their growing interdependencies have to be collectively analyzed and controlled for Smarter Cities.

We conclude with three programmatic thrusts already underway – Transactive Control for Transportation, Sustainable and Resilient Urban Water Systems, and Control in the Transportation-Electricity Nexus. The TC warmly and urgently seeks members working in these areas or motivated to start new thrusts.

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1 http://www.latimes.com/local/california/la-me-toilet-to-tap-20150525-story.html - page=1

2 http://www.washingtonpost.com/news/wonkblog/wp/2013/08/07/why-arent-young-people-getting-drivers-licenses-too-much-hassle/

3 http://www.shareable.net/blog/a-self-driving-future-at-the-intersection-of-driverless-cars-and-car-sharing

4 https://asunews.asu.edu/20140514-ac-nighttime-temps

Transactive Control for Transportation: The central entity in a Smart City, the human, enables myriad interconnections and interdependence through smart phones, social networks, and satellite-based navigation and introduces complex and compelling dynamics. Transactive control uses economic incentives to manage demand in the presence of scarce resources. With its beginnings in electricity markets [2,3], the idea is to combine economic incentives together with an understanding of the underlying structure of the infrastructure. It is estimated that 30% of traffic congestion in the city center is caused by the search for parking [4,5]. The transactive approach manages demand through dynamic pricing [6,7]. Underlying models capture not only available resources and demand patterns but also behavioral features of drivers making economic decisions. Our transactive control work currently targets Smart Parking [5,7] and Dynamic Tolling [8].

Sustainable and Resilient Urban Water Systems: Our urban water systems are facing three major challenges: growing demand due to rapid urbanization, depleting water resources, and deteriorating water transmission and distribution networks. Water resources and systems also face threats of disruptions due to natural disasters, and more recently, to malicious cyber-physical attacks. Ensuring safe, clean, and reliable water supply to our cities requires exploring new opportunities and justifying investment in them. Chief among these are new water treatment and desalination plants, efficient and cost-effective design of water supply networks, and management of problems related to water quality and losses such as leaks and bursts. The deployment of modern technologies for monitoring and diagnostics, combined with better strategies for network control and demand management, can significantly improve the operational efficiency of water systems and reduce the risks of service disruptions.

Control in the Transportation-Electricity Nexus: The transportation and electric grid infrastructures have traditionally been decoupled. Electrified transportation will fundamentally alter these urban infrastructures by creating new loads and interconnected spatio-temporal dynamics. This interconnected vehicle-grid system creates new mobility options and constraints while simultaneously imposing unique energy demand and storage opportunities [9]. Engineering a sustainable urban vehicle-grid system requires a cross-disciplinary approach that integrates transportation and power systems with control theoretic approaches. In parallel, the ubiquity of connected devices, open data platforms, modeling, and simulation allows a cyber-enabled approach to reliable planning and management of vehicle-grid systems. Motivated by these technological innovations and infrastructure transformations, this thrust explores how plug-in electric vehicles (PEVs) couple the dynamics of power systems, buildings, and transportation networks. We are exploring three concrete control problems within urban settings. The first is coordinated PEV charging for grid services[10,11,12]. The second problem is building energy management with PEV energy storage [13,14]. The last problem is optimal routing of PEV fleets [15,16].

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