Predictable Wireless Networking for Microgrids with Electrical Vehicles

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Smart grid wireless networks. Embedded wireless networks are expected to be basic components of smart grid communication infrastructures. For instance, wireless networks have already been used extensively in advanced metering, and they are expected to support not only real-time sensing and control of power generation, delivery, and storage but also health monitoring of the power grid infrastructure itself. For sustainable transportation, various types of electrical vehicles (including hybrid electrical vehicles, plug-in hybrid electrical vehicles, and all-electric vehicles) will be deployed more and more widely in the foreseeable future. Electrical vehicles not only serve as demanding electricity load, they are expected to serve as distributed, large-scale electricity storage systems too. Thus inter-vehicle wireless networking will be used not only for mobility-oriented network vehicle control but also for networked energy management, including charging and discharging control in the context of vehicle-grid integration.

Dynamics and uncertainties. In supporting mission-critical tasks such as microgrid and electrical vehicle control, smart grid wireless networks need to ensure predictable reliability, timeliness, and throughput in wireless messaging. Nonetheless, wireless messaging is subject to inherent uncertainties and dynamics within the system itself and from the environment.

Within the system, wireless communication assumes complex spatial and temporal dynamics due to unpredictable channel fading, network traffic pattern can be dynamic due to event-triggered data traffic and varying applications, and application requirements on messaging quality (e.g., throughput, latency, and/or reliability) may also vary over time and across different applications (e.g., from mobility control to energy management for inter-vehicle wireless networks). Moreover, different dynamics may well interact with one another to yield complex behavior. For instance, dynamics in network traffic pattern introduce dynamics in co-channel interference and thus dynamics in wireless link properties (e.g., reliability), which in turn affect link estimation and messaging in wireless networks [2, 4].

From the environment, a wide variety of factors affect the behavior of wireless messaging. Environmental factors such as temperature and humidity can affect wireless communication, moving objects may introduce unpredictable dynamics to wireless communication, co-existing wireless networks may interfere with message passing, and malicious attackers may try to jam a network.

Unlike the faults/perturbations considered in most traditional fault-tolerant systems, dynamics in wireless networks occur at multiple timescales at the same time. At longer timescales, there exist temporal link dynamics due to changing environment (e.g., temperature, humidity), long-lived traffic flows may come and go, and application QoS requirements may change. In the mean time, there exist dynamics that happen at very short timescale (e.g., in milliseconds), and they include fast channel fading, bursty traffic variation, and transient link perturbations due to human/object movement.

Besides differences in root-causes and frequencies, dynamics also differ in terms of controllability. Some dynamics are controllable, whereas others are uncontrollable. For instance, co-channel interference from concurrent transmitters can be controlled, so is network traffic pattern. On the other hand, many dynamics are uncontrollable, and they include dynamic wireless channel fading, interference from co-existing networks or jamming attackers, as well as unpredictable sensing events.

These multi-dimensional dynamics introduce complex uncertainties in smart grid wireless networks, and they challenge the traditional wisdom of network system design. To enable dependable messaging and predictable behavior of smart grid wireless networking, therefore, it is important to re-think systems design to address these complex dynamics.

Predictable wireless networking. To enable predictable wireless messaging in smart grid, we need to take a holistic approach to addressing the impact of complex dynamics and uncertainties on wireless messaging. More specifically, we need to integrate the life cycle of requirement engineering, capacity planning, protocol and system design, system analysis and performance evaluation to effectively take into account the dynamics and uncertainties in the design, analysis, and evaluation of automotive CPS. In addressing the dynamics and uncertainties in smart grid wireless networking, we should also try to take advantage of the unique properties of smart grid networking. For instance, the potentially periodic, predictable control data samples may enable effective scheduling mechanisms for dealing with co-channel interference. In addressing the dynamics and uncertainties, we should also leverage the new advances in the modeling and protocol design for wireless networked sensing and control, for instance, interference modeling for distributed protocol design [3] and multi-timescale approaches to real-time data delivery [1].

Due to the dynamics and uncertainties in smart grid wireless networks, we expect wireless communication properties (e.g., reliability, delay, and throughput) to be inherently probabilistic, thus any guarantees on wireless communication properties tend to be probabilistic in nature too. Since traditional networked control design methods have been mostly based on deterministic (worst-case) delay, there is a dire need for new paradigms of networked control that can effectively integrate with probabilistic communication quality guarantees.

References

[1] X. Liu, H. Zhang, Q. Xiang, X. Che, and X. Ju. Taming uncertainties in real-time routing for wireless networked sensing and control. *IEEE Transactions on Smart Grid (TSG)*, 2012.

[2] H. Zhang, A. Arora, and P. Sinha. Link estimation and routing in sensor network backbones: Beacon-based or data-driven? *IEEE Transactions on Mobile Computing*, 8(5):653 – 667, May 2009.

[3] H. Zhang, X. Che, X. Liu, and X. Ju. Adaptive instantiation of the protocol interference model in wireless networked sensing and control. *ACM Transactions on Sensor Networks (TOSN)*, in press.

[4] H. Zhang, L. Sang, and A. Arora. Comparison of data-drive link estimation methods in low-power wireless networks. *IEEE Transactions on Mobile Computing*, 9(11):1634–1648, November 2010.