Title

Interpreting Sensor Information in Large-Scale Distributed Cyber-Physical Systems

Author

Nauman Javed, *University of Massachusetts - Amherst*

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First Advisor

Tilman Wolf

Second Advisor

Michael Zink

Third Advisor

Christopher V. Hollot

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Abstract

Devices that sense some aspect of the environment, or collect data about it, process the sensed data to produce useful information, and possibly take actions based on this in- formation to effect desired changes in the environment are becoming ubiquitous. There are numerous examples of such "Cyber-Physical Systems," such as, weather sensors dis- tributed geographically to sense various weather parameters like temperature, air pressure, humidity etc, sensors used at different levels of the energy grid, from power generation to distribution to consumption, that monitor energy production and usage patterns, sen- sors used in various military and civilian surveillance and tracking applications etc. This dissertation focuses on "Distributed Cyber-Physical Systems," the ones that have multiple sensors distributed geographically or spatially. The sensors comprising such Distributed Cyber-Physical Systems may or may not be networked together, although their main pur- pose is to provide localized information to be ultimately fused into an overall picture of the whole geographical space covered by the sensors. This dissertation explores ways of interpreting information in such Distributed Cyber-Physical Systems. In this context, we look at three related problems.

The first one is a multiple target localization and tracking problem in a wireless sensor network comprising binary proximity sensors [38]. We analyze this problem using the geometry of sensing of the individual sensors, and apply graph theoretical concepts to develop a fully-distributed multiple, interfering, target localization and tracking algorithm. Our distributed algorithm demonstrates the power of the use of localized information by sensors to make decisions that contribute to the inference about phenomena, in this case target movement, that are essentially global in nature. The distributed implementation of information interpretation also lends efficiency advantages, such as more efficient energy consumption due to reduced communication requirements, as shown in our simulations.

While the first two problems in this dissertation, as described above, deal with sensor information in one domain, target tracking in one case and weather sensing in the other, the third problem we investigate is cross-domain [36]. Here, parameters of one domain affect parameters of another domain, but only the affected domain parameters are measured, and tracked, to ultimately control these parameters in the affected domain. Specifically, we develop methods of network configuration based on distributed estimation and prediction of network performance degradataion parameters, where this performance degradation is originally affected by external environmental parameters such as weather conditions. We take "Routing in Wirelss Mesh Networks in the Face of Adverse Weather Conditions" as an example application to demonstrate our ideas of predictive network configuration. Through the simulations generated using real-world weather data, we are able to show that localized estimation and prediction of wireless link quality, as affected by the extreme weather events, results in remarkable improvements in network routing performance, and performs equally well, or even better, than routing that uses predictions of the affecting weather itself.

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