CPS: Small: Collaborative Research: Localization and System Services for SpatioTemporal Actions in Cyber-Physical Systems

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ABSTRACT

The ongoing project addresses the problem of how to locate and identify events of interest in tracking analysis and control applications within cyber-physical systems. The project seeks to model mobility and localization of computation in cyber-physical systems. We use these objects to define an architectural framework in which events and actions are located in physical/logical space and time. Our current research focus is on synchronization, localization methods and protocols that make accurate cyber-physical addressing possible. We use spatiotemporal events in building collaborative distributed real-time control applications drawn from intermodal transportation systems. Going forward we seek to devise a framework for building predictable and reliable cyber-physical application services and an operating environment for these services.

Our work on clock synchronization focuses on obtaining guarantees on the worst case synchronization accuracy. Building upon the causality relationship in message exchanges and using properties of crystal oscillators, we have successfully designed and implemented the synchronization protocol that provides much tighter accuracy guarantees than conventional methods. Regression-based clock estimation has also been incorporated into the protocol to enable good estimate and worst case guarantee simultaneously.

The work on sensor localization also focuses on obtaining the worst case accuracy guarantee. We have devised an SDP formulation and found several analytical results for unique localizability of nodes. For scalability, we have designed an iterative algorithm for large networks, where we calculate the localization error bound for a subgraph that contains the node of interest and then gradually increase the size of the subgraph to improve the bound.

For networked CPS applications, protocol configuration is a key aspect in achieving high assurance. Appropriate selection of protocol configuration parameters in turn is dependent upon the network configuration at hand, expressed for instance in terms of traffic flows, node densities, etc. Experience has shown that network configurations vary substantially from application to application and instance to instance. We focused on configuration techniques at the level of medium access control (MAC) and routing networking protocols.

For the case of MAC, we systematically studied the question of how to choose a MAC protocol as well as its parameter values when deploying a wireless sensor network (WSN) application or adapting it online, as follows. We introduced a framework for performance modeling of classes of MAC protocols. We used this framework to analyze various performance metrics comprehensively across the configuration space of the protocols; extensive experimentation corroborates our analysis. Our results serve not only as a basis for choosing protocols and parameters, they also yield insight into how to adapt MACs for changing traffics. A surprising finding of our comparative evaluation is that one class of MAC protocols consistently achieves the best or second best performance for various metrics across much of the configuration space thus pointing to networking solutions that are specific to CPS needs.

For the case of routing, we focused on the feasibility of predictable performance in target environments which are physically different from the test environment. Specifically we proposed a method to achieve performance repeatability across test and target environments, which relies on analytical prediction of expected protocol performance as a function of RF environment parameters and forwarding protocol. Towards validation of the proposed method across diverse set of RF environments, we obtained analytical, simulation, and experimental results for routing in one-dimensional networks deployed in indoor and outdoor propagation environments, and for two-dimensional networks on four major indoor WSN testbeds.