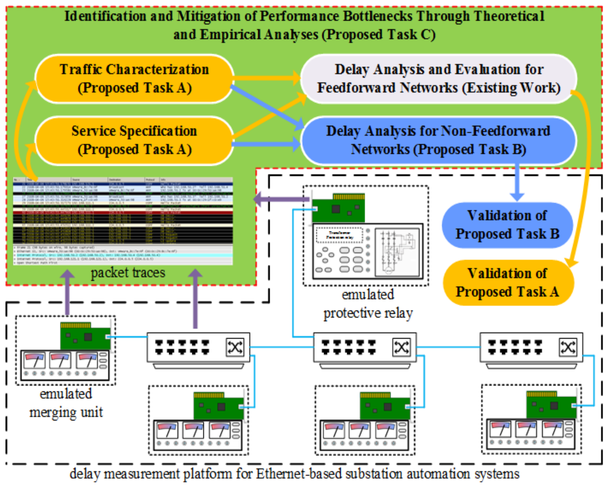
CPS: Breakthrough: Analysis, Identification and Mitigation of Delay Performance Bottlenecks of Network Infrastructure in Cyber-Physical Systems

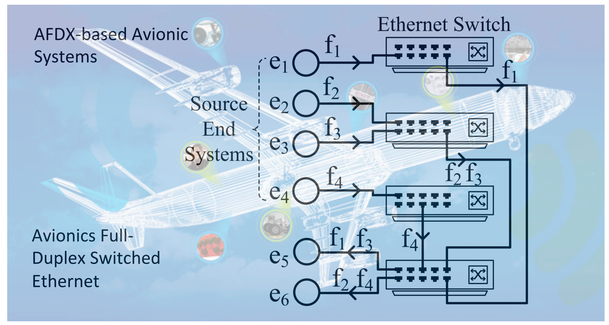
Principal Investigator: Dr. Liang Cheng, Lehigh University
http://liangcheng.info/projects/cps-breakthrough/

Mission-critical Cyber-Physical Systems (CPS) applications, such as industrial control and avionics systems, require their network infrastructure to provide deterministic delay performance. However, the problem of analyzing, identifying and mitigating delay performance bottlenecks in CPS remains largely unexplored due to the lack of suitable frameworks for these tasks.

Challenges: Deterministic delay performance analysis for interdependent flows in CPS; Scalable identification of delay performance bottlenecks; Adaptive mitigation of delay performance issues.



Scientific Impact: Establishing a systematic approach to the design, characterization, and refinement of network infrastructure in CPS; Network calculus analysis for non-feedforward networks in feedback control CPS.



Solutions: Network-calculus-based modeling from measurements is integrated with theoretical analyses of network calculus; Converting non-feedforward network traffic patterns to feedforward ones allows network calculus to analyze feedback control networks; A TSN management system with optimized path and timing for collecting delay performance data to identify bottlenecks and machine learning based control to mitigate issues caused by the performance bottlenecks.

Stakeholder	Benefit
CPS architects and engineers	1. Estimated worst-case delay bounds at early stages of networked CPS design, guiding the design process to ensure that hard-real-time constraints are met 2. Accurate delay bounds under different CPS operational scenarios using measurement-based models constructed for procured equipment 3. Accurate worst-case delay analyses throughout the life cycle of networked CPS to provide guidance on mitigating/eliminating performance bottlenecks
CPS operators	1. Worst-case delay bounds re-computed upon system changes (e.g., after new services are added or legacy devices are replaced) without interrupting system operations, allowing quick verifications of hard-real-time safety properties 2. Worst-case delay bounds provided in a flow-specific fashion, making it easier to identify causes to delay-induced system failures (as well as delay performance bottlenecks)

Broader Impact: Potential influence on industry practice related to AFDX and TSN; Training opportunities for 9 graduate and undergraduate students; 2 survey papers and 1 tutorial so far

B. Zhou, I. Howenstine, S. Limprapaipong, and L. Cheng. A Survey on Network Calculus Tools for Network Infrastructure in Real-time Systems. IEEE Access, 2020.

L. Cheng and S. Bondorf. Modeling and Analysis of Network Infrastructure in Cyber-Physical Systems. A tutorial at ACM SIGCOMM 2019, August 23, 2019.

Publications (A partial list)

H. Yang, L. Cheng, and X. Ma. Combining Measurements and Network Calculus in Worst-Case Delay Analyses for Networked Cyber-Physical Systems. IEEE INFOCOM'19 Poster, 2019.

H. Yang, L. Cheng, and X. Ma. Bounding Network-induced Delays for Time-critical Services in Avionic Systems using Measurements and Network Calculus. Proceedings of 10th ACM/IEEE International Conference on Cyber-Physical Systems, WiP, 2019.

H. Yang and L. Cheng. Bounding Network-Induced Delays of Wireless PRP Infrastructure for Industrial Control Systems. 2019 IEEE International Conference on Communications (ICC'19), 2019.

B. Zhou and L. Cheng. A Reality-Conforming Approach for QoS Performance Analysis of AFDX in Cyber-Physical Avionics Systems. IEEE/ACM International Symposium on Quality of Service, 2021.

2021 NSF Cyber-Physical Systems Principal Investigators' Meeting
June 2-4, 2021

LEHIGH UNIVERSITY

LONG LAB
LEARNING AND OPTIMIZATION ON NETWORKS AND GRAPHS

NSF

Award ID#: 1646458